Characterization And Evaluation Of Acid Rain In Central Florida From 1978 to 1987

Ten-Year Summary Report

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INTRODUCTION

During the past decade, an increasing concern about acid rain has prompted extensive research and monitoring activities which have been designed to provide a better understanding of cause and effect processes and to measure current levels of acid rain. During the mid 1970's, the National Aeronautics and Space Administration (NASA) funded an extensive environmental monitoring program (1) which included a substantial acid rain monitoring component. That program provides the initial basis for findings summarized in this report. The University of Central Florida (UCF) provided technical assistance for the program and was responsible for monitoring activities. A multi-site network was established at or near the Kennedy Space Center (KSC) and one additional site was established on the UCF campus located near Orlando, Florida. These activities continued until October 1981 when KSC monitoring responsibilities were absorbed by other NASA contractors and the number of operational sites was reduced. The site at UCF was retained to be operated by UCF personnel. In late 1983 the primary KSC site was converted to be operated as a National Atmospheric Deposition Program (NADP) site.

Several contract reports (2, 3) and one NASA Technical Memorandum (4) have been written which address various aspects of the monitoring effort. The UCF site has now been operated in continuous fashion for more than 10 years. One KSC site, whose location has been changed only slightly, has also been operated over the same time period. Unfortunately, monitoring data from the KSC site for the period November 1981 to late 1983 have been determined to be of lesser quality than that of other data (4) and are therefore not included in this current data summary and evaluation.

METHODS AND PROCEDURES

Sampling Locations

Site locations and periods of operation as they pertain to data and results described in this report are presented in Figure 1. The UCF site has been located on the roof of the Chemistry Building during most of the study period. During the initial phase of the study, the site was located 0.9 km south of the current site in a grassy field near the UCF Physical Plant Headquarters and was relocated to the roof of the Chemistry Building in June 1979. During September and October 1982 the collector was located on the roof of the UCF Biology Building located 70 m east of the Chemistry Building. The National Weather Service Office (NWS) at Orlando International Airport, where rainfall amount measurements have been made for several decades, is located 21 km south-southwest of the UCF campus, which is located at 28°35'59" N latitude and 81°12'00" W longitude. The KSC site 13, which operated during 1977-1981, was located at 28°31'48" N latitude and 80°39'44" W longitude. The KSC NADP site, which has operated from late 1983 to the present, is located 2.3 km northeast of site 13 at 28°32'33" N and 80°38'39" W.

Sample Collector and Collection Interval

Aerochem Metrics wet-dry collectors have been used exclusively for collection of rainwater samples. Collection intervals have typically been 24 hr. periods ending on Tuesdays through Friday and 72 hr. periods ending on Mondays for samples collected at UCF. Similar collection intervals were used at KSC prior to establishment of the NADP site. The NADP site sampling interval length is seven days ending on Tuesdays mornings. The KSC site has been operated with this seven day interval since late 1983.

Sample Handling and Chemical Analysis

The protocol for working with collected samples has been described (5). Methods for the measurement of the major ion chemical composition of rainwater samples as part of the UCF/KSC program and the NADP program have been described (5, 6). Methods employed are summarized in Table 1. Data quality has been evaluated by examining a number of diagnostic ratios, e.g. anion/cation ratio, measured/calculated conductivity, Cl/Na, and Na/Mg on an individual sample basis (7).

RESULTS AND DISCUSSION

Sample Collection History

Collection of rainfall on the UCF campus began in July 1977 and has continued in uninterrupted fashion. Only sample amount, pH, and conductivity were measured until November 1977. Since November 1977, major cation and major anion concentrations as well as pH and conductivity have been measured. Sample collection began at site 13 of the UCF/KSC network in late summer 1977. Measurement of all major chemical species, pH, and conductivity started in November 1977 and were completed on samples collected at that site through the end of October 1981. Sampling for the NADP site commenced in the fall of 1983. Results obtained for samples collected at these KSC sites during 1978-1981 and 1984-1987 are included in this report.

General Rainfall Composition

The general chemical composition of rainfall collected at UCF is summarized by year and for the period 1978-1987 in Table 2. A similar summary for the KSC/NADP site for the periods 1978-1981 and 1984-1987 and for the eight year period is presented in Table 3. Several figures are used to display the annual volume weighted average composition and annual total deposition for several species determined in samples collected at both sites. Monthly volume weighted average composition and annual total deposition based on 10 years of continuous data for the UCF site and for the 8 years of data from the KSC/NADP site are also presented graphically.

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The presentation of monitoring data such as that included in tables 2 and 3 does not allow one to portray the variability in rainfall chemical composition that occurs on an individual sample or individual storm basis. It has been observed that concentrations of each of the major cations and anions present in rain collected at UCF and at KSC can vary over two to three orders of magnitude. The measured pH of more than 800 samples collected at UCF during this 10 year period is summarized in Figure 2. The measured pH of more than 280 samples collected at KSC site 13 and more than 180 samples collected at the KSC/NADP site are also presented in Figure 2. The median pH at both sites is 4.52 and the distribution of measured pH is quite similar at both sites. It should be emphasized that sampling at the NADP site occurs at weekly intervals while sampling at UCF and KSC site 13 have typically occurred at one or three day intervals. The variability in major cation and anion concentrations in the UCF samples are presented in figures 3 and 4. All ions have similar distribution patterns. Marine salts, specifically sodium ion and chloride ion, show the greatest variability particularly at high concentrations. The most abundant anion is excess sulfate and the most abundant cation is hydrogen ion.

Measured sample acidity and conductivity are influenced to some degree by all ionic components present in each rain sample. Stepwise multiple regression has been used to evaluate the dependence of individual sample acidity upon the presence and concentration of major anions and cations. Independent variables considered in this treatment include sodium, potassium, calcium, magnesium, ammonium ion, chloride, nitrate, and excess sulfate. Excess sulfate is measured total sulfate after correction for the presence of marine derived sulfate (8). Independent variables are presented in Table 4 in the order selected by the stepwise regression procedure. The model equations suggest that individual sample acidity is accounted for by the selected independent variables and these account for between 84% and 99% of the variance observed in individual sample acidity at UCF and 68% to 94% at KSC during annual time periods. The stepwise regression equations obtained from the entire 10 year and 8 year data sets for UCF and KSC, respectively, are presented in Table 5. Similar stepwise regression equations are obtained for both sites. The influence upon acidity by the major anions, excess sulfate and nitrate, and the neutralizing cations, calcium and ammonium ion, is clearly illustrated. Graphical presentation of the relationship between measured individual sample acidity for samples collected at UCF during the 10 year period and calculated acidity based on the obtained stepwise regression equation is shown in Figure 5.

The amount of rainfall which falls within Florida is characterized by extreme variability. This variability occurs statewide and on a small regional basis. As an example, consider the following measurements: Total rainfall for the month of August 1985 was recorded as 39.41 cm at UCF, 16.74 cm at the KSC/NADP site, and 29.54 cm at the Orlando NWS. Documentation of this variability is illustrated in Figure 6 where annual amounts of rainfall at UCF, at KSC, and at the NWS office from 1978 to 1987 are compared. The 30 year NWS annual average of 121.6 cm is also shown. During 1978 to 1987, both the UCF and NWS sites received approximately 15% greater rainfall than the 30 year average, while the KSC site received an amount equal to the 30 year average. In fact, the UCF site received

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less than the 30 year average only during 1980 and 1981. Total rainfall amounts can therefore have considerable influence on acid deposition variability over small geographical distances.

Seasonal variability in rainfall amounts is also quite high. Monthly average rainfall amounts for the period 1978 to 1987 are shown in Figure 7. The summer months July through September provide considerably greater amounts of rain. In general, the amount of rain received at UCF has been greater than that received at KSC during the summer months, but the opposite behavior has been observed during the cool weather months.

Rainfall Acidity

The volume weighted acidity of rain at both UCF and KSC since 1977 is 26 μN which represents a pH of 4.58. Annual weighted average hydrogen ion concentration and annual hydrogen ion deposition are presented in figures 8 and 9, respectively. The acidity of rain was greater than the 10 year average during the first 5 years of the study and below this value since 1983 with the exception of 1986. The highest acidity was during 1978 at both sites and the lowest acidity occurred during 1984 at both sites. Annual deposition of acid has averaged 37 and 31 meq/m^2 at UCF and KSC, respectively, during the 10 year and 8 year study periods. In general, deposition amount has been greatest early and late in the 10 year period with lesser amounts being observed during middle years. The year 1982 was an exception. Annual rainfall amounts have varied by a factor of nearly two (see 1981 vs 1985 at UCF) and this variability exerts a substantial influence on deposition quantities. Deposition of acid during 1985 at UCF was about average in spite of the fact that pH was 0.08 units higher than average. Total acid deposition has been greater at UCF than at KSC in each year with the exception of 1987. The UCF site has received greater rainfall amounts in all years except 1987 which accounts for the differences in total acid deposition. Measured acidity at these sites is approximately one-half of that observed in the midwest and northeastern sections of the U.S. The deposition is greater than one-half the quantity that is received in the northeast because of the greater amounts of rain received in Florida.

Acidity results used as the basis for the discussion presented in the previous paragraph are based on field measurements (9). NADP laboratory measurements of acidity for samples collected at KSC during 1984 to 1987 are about 25% lower than the corresponding field acidity measurements. These findings are summarized in Table 4. Differences between field measured acidity and laboratory measured acidity are typically observed as part of all acid deposition measurements associated with the NADP program (9) and the discrepancy has not been totally resolved. If appropriate quality control procedures are in place, then it is likely that the field acidity measurements will more correctly represent the acidity of rain because minimal time lag is associated with field measurements compared to laboratory measurements.

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Anion Concentrations in Rain

The stepwise regression analysis that has been discussed previously suggests that nitrate and sulfate concentrations in rain are important predictors of sample acidity. These anions are present in rain in amounts that are more than sufficient to account for measured acidity. Excess sulfate is the most plentiful anion in rain collected at UCF and nitrate concentrations are somewhat smaller than chloride. It has been shown previously that the chloride concentrations typically observed in rain in east-central Florida can be accounted for by marine influences associated with site proximity to the ocean (10). Comparisons by year for these anions are shown in figures 10 and 11. Chloride is the dominant anion observed in rain collected at KSC and nitrate ion is the least plentiful anion. The sulfate to nitrate ratio approaches a value of two in rainfall collected in the eastern U.S. (11). This ratio for rainfall collected at UCF and at KSC is summarized by year and by month in figures 12 and 13, respectively. The ratio has shown a general decline over the period 1978 to 1987 and the decline is most apparent in samples collected at UCF. During 1986 and 1987, the ratio has approached a value of one. When compared with acidity and nitrate levels over the same time period, it appears that the observed decrease in acidity is accounted for by the decrease in observed excess sulfate concentrations. When the excess sulfate to nitrate ratio is considered by month, it is observed that the KSC site yields a consistently greater ratio than for the UCF site. Large extremes from month to month are not observed; however, lowest values are typically observed from May to October.

Annual weighted average nitrate and excess sulfate concentrations for the 10 year period are approximately 30% and 4% greater, respectively, at UCF than at KSC. Figures 14 and 15 illustrate the 10 year pattern. Nitrate concentrations have remained relatively constant from year to year; however, there seems to be a substantial increase in concentration at UCF during 1986 and 1987. Excess sulfate concentrations have decreased substantially from concentrations measured prior to 1983 at both KSC and UCF.

A seasonal pattern is quite apparent when nitrate and excess sulfate concentrations for the 10 year period are summarized by month, see Figure 16. Concentrations for both anions exhibit summertime highs which are double the concentrations that are measured during October through January. This observation is consistent with those made by others (11) who find that relatively high summertime acidity is accompanied by higher concentrations of nitrate and sulfate.

Ammonium Ion Concentrations in Rain

The monthly variations that are observed for acidity, nitrate, and sulfate concentrations are characterized by summertime maxima. Monthly variations in ammonium ion concentration, presented in Figure 16, are similar to those observed for the other chemical species; however, the maximum monthly concentrations appear two or three months earlier during April and May than do the maxima for nitrate and excess sulfate. The extreme ammonium ion concentration observed at UCF during April is similar to the April maximum extreme observed for excess

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sulfate. The presence of ammonium ion suggests the presence of strong acid, e.g., sulfuric acid which has been neutralized by ammonia to form the ammonium ion. Annual ammonium ion concentrations, presented in Figure 17, have varied from 22 μN during 1981 to 2 μN during 1985 at KSC. During 1980 and 1981 when annual ammonium ion concentrations were highest, the annual excess sulfate concentrations were also observed to be the highest of the 10 year period.

Marine Influence on the Ionic Composition of Rain

The influence of site proximity to the ocean on ionic composition has been noted earlier in this report. Sea salts contribute the following ions to rainwater in order of decreasing importance: Chloride, sodium, magnesium, calcium, sulfate, and potassium. The Cl/Na ratio consistently approaches the ratio of 1.16 (eq./eq.) present in seawater (see appendix I) which suggests that the concentrations of chloride and sodium measured in rain are a consequence of the marine influence. For this reason, chloride concentration and deposition can be used as a general measure of the marine influence. The monthly chloride concentrations displayed in Figure 18 exhibit a pronounced cool weather maximum and warm weather minimum. Prevailing winds and reinforcing weather patterns tend to occur from the north and east during the fall and winter, and therefore can project the marine influence from the Florida east coast inland. The monthly deposition of chloride is compared with acid deposition and total rainfall amounts in Figure 19. This comparison clearly shows the contrasting behavior that has been observed for the marine influence and acid related components of rainwater ion composition.

SUMMARY

The results of 10 years of monitoring the chemical composition of rain in east-central Florida have shown that the rain is moderately acid. Although the measured acidity is less than that observed in other regions of the U.S., it does suggest that the environmental impact of acid rain may eventually reach central Florida, if it has not yet begun. The annual chemical composition of rain at UCF and at KSC has shown moderate variability. Extreme daily and monthly variations have been observed; however, these variations have not been addressed specifically in this report. Trends toward increased or decreased acidity of total ionic composition have not been established, although it is quite apparent that acidity during recent years has decreased. Total acid deposition has not shown a comparable decrease, because rainfall amounts have increased in recent years compared to early years in the study period. The total ionic composition of rain collected at KSC is greater than that for rain collected at UCF; however, this can be accounted for by site proximity to the ocean with the accompanying marine influence.

REFERENCES

1.   Madsen, B.C. 1979. Chemical studies of rainfall and soils. Vol. 2. A continuation of baseline studies for environmentally monitoring space transportation systems (STS) at John F. Kennedy Space Center. Contract No. NAS10-8986. Final report to NASA, John F. Kennedy Space Center, FL.

2.   Madsen, B.C. 1981. Kennedy Space Center precipitation monitoring program. Contract No. NAS10-9841. Contract Report to NASA, John F. Kennedy Space Center, FL.

3.   Madsen, B.C. 1985. Characterization and evaluation of acid rain at a site remote from the Kennedy Space Center. Contract No. NAS10-10390. Final Contract Report to NASA, John F. Kennedy Space Center, FL.

4.   Madsen, B.C., T.W. Dreschel, and C.R. Hinkle. 1986. An evaluation of rain chemistry data for the John F. Kennedy Space Center, Florida and the University of Central Florida, Orlando, Florida. NASA Technical Memorandum 100301.

5.   Madsen, B.C. 1981. Methods manual for the Kennedy Space Center precipitation chemistry laboratory. Contract No. NAS10-9841. NASA, John F. Kennedy Space Center, FL.

6.   National Atmospheric Deposition Program. 1984. Quality assurance plan-deposition monitoring. NADP

7.   Galloway, J.N. and G.E. Likens. 1978. The collection of precipitation for chemical analysis. Tellus 30:71-82.

8.   Madsen, B.C. 1981. Acid rain at Kennedy Space Center, Florida: recent observations. Atmos. Environ. 15:853-862.

9.   Keene, W.C. and J.N. Galloway. 1984. Organic acidity in precipitation in North America. Atmos. Environ. 18:2641-2647.

10.   Madsen, B.C. 1984. Comparison of wet deposition at coastal and inland sites in east-central Florida. In: B.B. Hicks (ed.), Deposition both wet and dry. Acid Precipitation Series, Vol. 4. Butterworth Publ.

11.   Dana, M.T. and R.C. Easter. 1987. Statistical summary and analysis of event precipitation chemistry from the MAP3S network, 1976-1983. Atmos. Environ. 21:113-128.

Table 1. Methods of Chemical Analysis

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Chemical Species	UCF/KSC Method	NADP Method
pH	glass electrode	glass electrode
Conductivity	electrode	electrode
Na	IC* ,FE**	AA
K	IC* ,FE**	AA
Ca	AA	AA
Mg	AA	AA
NH_4	IC* ,FIA***	TC
Cl	IC* ,FIA***	IC
NO_3	IC* ,FIA***	IC
SO_4	IC* ,FIA***	IC

- -

*	IC	Ion chromatography 11/77-10/81
**	FE	Flame emission spectroscopy 11/81-present
***	FIA	Flow injection analysis-Colorimetry 11/81-present
	AA	Atomic Absorption Spectrophotometry
	TC	Technicon Autoanalyzer Colorimetry

TABLE 2.   ANNUAL AND CUMULATIVE RAINFALL CHEMISTRY SUMMARIES FOR THE
UNIVERSITY OF CENTRAL FLORIDA

TIME PERIOD	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	07/77-12/87
No. of Samples	79	90	78	75	99	94	73	93	104	100	942
cm Rain/12 mos.	135.2	157.8	99.6	93.8	137.1	152.4	128.2	165.0	140.3	162.2	139.6
pH	4.47	4.49	4.54	4.54	4.50	4.72	4.71	4.66	4.54	4.69	4.58
Conductivity,uS/cm	15.4	15.4	16.0	18.8	18.4	19.2	16.3	16.0	17.5	14.8	16.2
Deposition Total (meq/m^2-yr)											
H	45.4	50.6	29.0	27.2	44.3	29.0	24.7	36.3	40.7	33.5	36.8
NH$_4$	11.7	13.8	12.0	15.3	14.3	11.1	11.1	14.5	10.4	12.3	12.4
NO$_3$	14.6	21.3	13.6	13.9	21.0	18.6	17.7	21.9	25.0	28.8	19.5
excess SO$_4$	36.7	41.3	30.5	27.7	46.2	29.3	31.5	37.6	33.5	26.8	33.9
Ionic Concentrations (µeq/L)											
H	33.6	32.1	29.1	29.0	32.0	19.1	19.3	22.0	29.0	20.6	26.6
Na	14.8	21.0	12.8	25.4	14.5	20.9	28.2	23.0	12.6	20.5	19.0
K	1.5	1.2	0.8	1.0	0.4	1.3	0.7	1.0	0.3	0.6	0.8
Ca	6.9	8.4	11.2	11.4	12.0	9.2	11.1	9.4	8.4	7.0	9.2
Mg	4.0	5.6	3.2	7.0	4.0	5.6	7.5	5.9	3.7	5.3	5.1
NH$_4$	8.6	8.7	12.1	16.3	10.3	7.3	8.6	8.8	7.4	7.6	9.0
Cl	15.9	24.6	13.9	29.8	18.6	25.4	33.8	29.0	16.8	22.2	22.7
NO$_3$	10.8	13.5	13.6	14.8	15.2	12.2	13.8	13.3	17.8	17.7	14.1
SO$_4$	28.8	28.6	32.0	32.4	35.4	21.6	27.9	25.5	25.4	18.6	26.7
excess SO$_4$	27.2	26.2	30.6	29.5	33.7	19.2	24.6	22.8	23.9	16.5	24.5

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TABLE 3. ANNUAL AND CUMULATIVE RAINFALL CHEMISTRY SUMMARIES FOR THE
KENNEDY SPACE CENTER (1978-1981 UCF SITE 13 and 1984-87 NADP SITE)

TIME PERIOD	1978	1979	1980	1981*	1984	1985	1986	1987	10/77-10/81	01/84-12/87	10/77-12/87 **
No. of Samples	80	77	79	43	46	46	48	48	303	188	491
cm Rain/12 mos.	121.6	148.6	101.6	65.9	120.2	120.2	103.7	167.9	115.0	127.7	121.6
Field pH	4.46	4.64	4.48	4.47	4.70	4.68	4.55	4.63	4.53	4.64	4.58
Lab pH	---	---	---	---	4.78	4.83	4.70	4.75	---	4.76	---
Field Cond.uS/cm	21.5	21.7	23.0	24.4	19.4	13.2	19.5	16.2	21.6	16.4	19.0
Lab Cond. uS/cm	---	---	---	---	18.5	13.4	18.3	15.1	---	16.6	---
Deposition Total (meq/m^2-yr)											
Field H	41.8	34.4	33.3	22.5	24.2	25.2	29.0	39.7	33.8	29.5	31.7
Lab H	---	---	---	---	20.0	17.8	20.7	30.2	---	22.2	---
NH$_4$	10.3	11.2	16.7	14.8	11.3	2.3	3.3	7.7	13.2	6.2	9.7
NO$_3$	14.4	15.9	14.4	9.6	12.6	9.4	10.5	16.4	13.8	12.2	13.0
excess SO$_4$	35.8	33.9	38.5	26.6	25.2	24.1	21.4	29.8	34.1	23.8	29.0
Ionic Concentrations (µeq/L)											
Field H	34.4	23.1	32.8	34.2	20.1	21.0	28.0	23.1	29.4	23.1	26.1
Lab H	---	---	---	---	16.6	14.8	20.0	17.3	---	17.3	---
Na	30.8	60.5	30.0	32.4	53.0	34.7	49.8	43.5	39.9	43.5	41.8
K	1.2	2.6	2.0	1.4	2.0	1.0	1.6	1.4	1.8	1.4	1.6
Ca	10.0	8.9	9.9	11.2	9.0	7.7	6.7	6.9	9.4	6.9	8.1
Mg	7.5	14.3	7.7	9.0	13.4	8.9	12.2	10.8	9.8	10.8	10.3
NH$_4$	8.5	7.5	16.4	22.4	9.4	1.9	3.1	4.8	1.4	4.8	8.0
Cl	33.0	63.3	31.6	37.8	63.4	42.1	59.3	52.0	42.5	52.0	47.4
NO$_3$	11.9	10.7	14.1	14.6	10.5	7.8	10.1	9.6	12.0	9.6	10.7
SO$_4$	32.7	29.3	41.1	44.0	27.3	20.0	26.5	23.8	33.9	23.8	28.6
excess SO$_4$	29.4	22.8	37.9	40.3	21.0	15.9	20.7	18.6	29.6	18.6	23.4

*   01/81 - 10/81 operation

** No data available 11/81-12/83

Table 4. IONIC PREDICTORS OF ACIDITY IN RAIN BASED ON A STEPWISE REGRESSION MODEL

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
UCF	$xsSO_4$	$xsSO_4$	$xsSO_4$	$xsSO_4$	$xsSO_4$	$xsSO_4$	NO_3	$xsSO_4$	NO_3	NO_3
	NO_3	$-Ca$	$-Ca$	$-NH_4$		$-Ca$	$-Ca$	$-Ca$	$xsSO_4$	$-Ca$
	$-Ca$	NO_3	NO_3	$-Ca$		NO_3	$xsSO_4$	NO_3	$-Ca$	Mg
	$-NH_4$	$-Cl$	$-NH_4$	NO_3		$-NH_4$		$-NH_4$	$-NH_4$	$xsSO_4$
										$-NH_4$
n/r^2	66/0.98	79/0.90	73/0.94	70/0.90	93/0.90	91/0.87	66/0.96	88/.084	93/0.95	89/0.96
KSC	$xsSO_4$	$xsSO_4$	$xsSO_4$	$-Ca$			$xsSO_4$	$xsSO_4$	$xsSO_4$	$xsSO_4$
	$-Ca$	$-Ca$	$-Ca$	$xsSO_4$				$-Ca$		NO_3
	NO_3	NO_3	NO_3	$-NH_4$						
	$-NH_4$	$-NH_4$	$-NH_4$	NO_3						
n/r^2	53/0.92	65/0.94	65/0.90	34/0.89			41/0.72	41/0.68	39/0.84	36/0.92

Independent variables are listed in the order selected by the stepwise regression procedure.
Significance levels for entry of 0.001 and 0.0005 for removal were utilized with the SAS procedure.

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Table 5.   STEPWISE REGRESSION EQUATION SUMMARIES

KSC (8 years)

Independent variable H

Dependent variable Partial r^2

$(0.86\pm0.03)xsSO_4$	(0.66)
$(-0.84\pm0.04)Ca$	(0.12)
$(0.75\pm0.04)NO_3$	(0.08)
$(-0.41\pm0.04)NH_4$	(0.03)
8.50	

$n=403$, $r^2=0.88$

UCF

Independent variable H

Dependent variable Partial r^2

$(0.89\pm0.01)xsSO_4$	(0.87)
$(-0.57\pm0.04)NH_4$	(0.02)
$(0.55\pm0.02)NO_3$	(0.03)
$(0.52\pm0.02)Ca$	(0.03)
$(0.13\pm0.02)Mg$	$(.004)$
5.76	

$n=817$, $r^2=0.94$

Figure 1. Collection Site Locations.

SITE OPERATION HISTORY

UCF	7/77 – Present
KSC13	9/77 – 10/81
NADP	11/83 – Present

LAUNCH
PAD 39A

28° 35′

Indian R.

NADP

KSC13

Banana R.

UCF

80° 40′
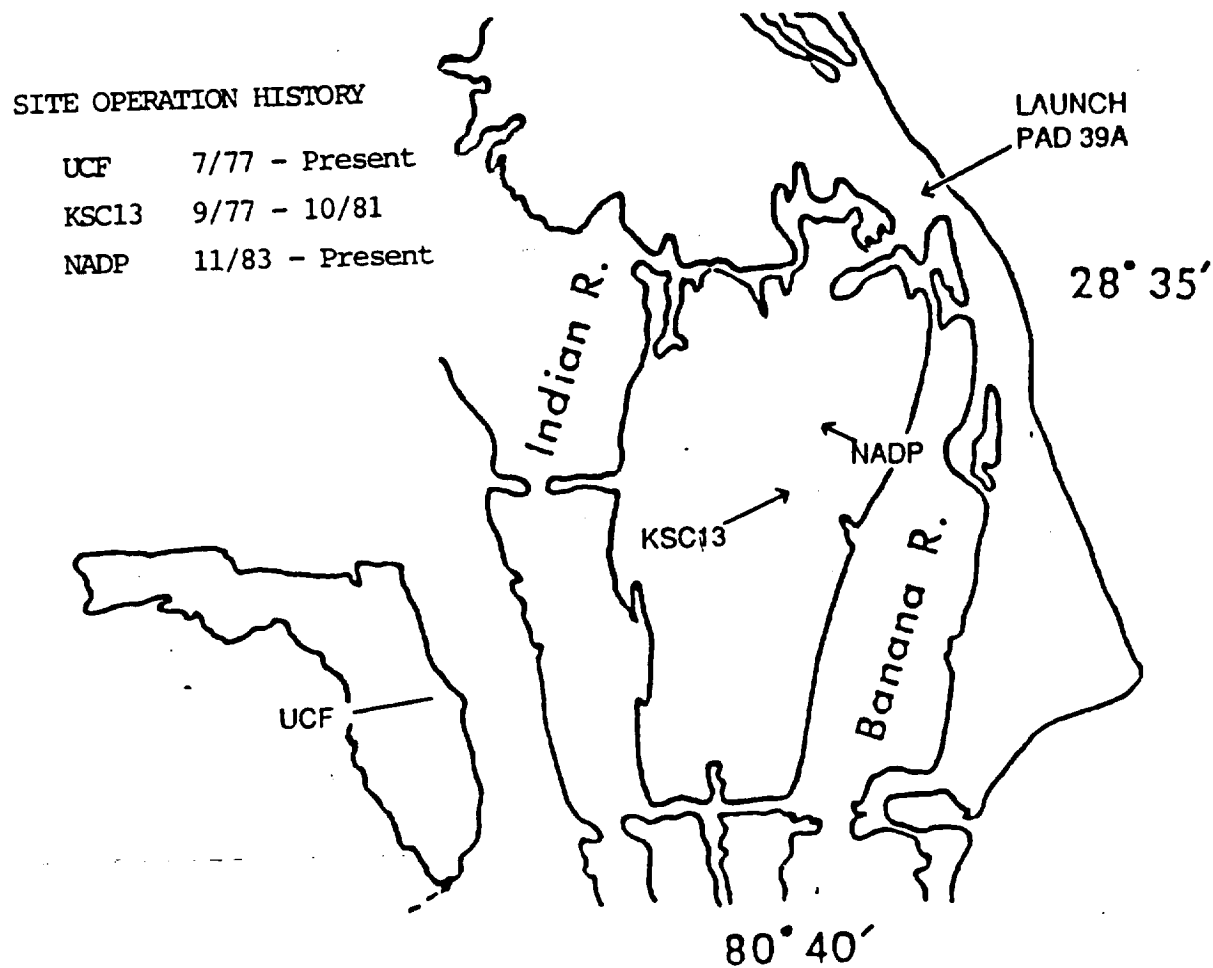
Figure 2. Ten Year Distribution of Rainwater Sample pH.

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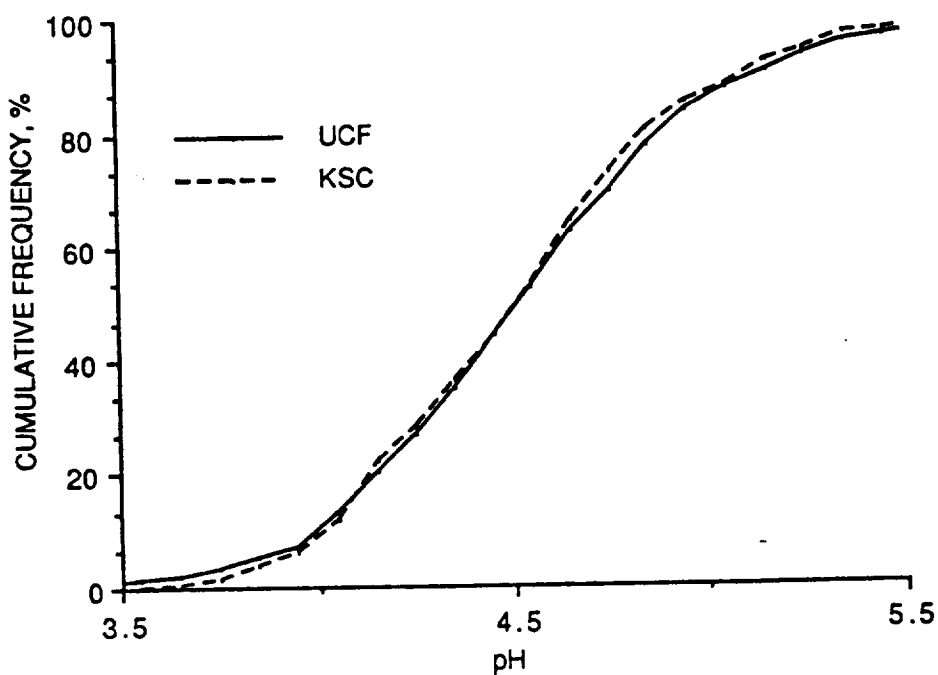
Figure 3. Ten Year Cation Concentration Distribution in Rain at UCF.

Legend:
- pH
- pNa
- pCa
- pNH4

Y-axis: CUMULATIVE FREQUENCY, %
X-axis: p(N)
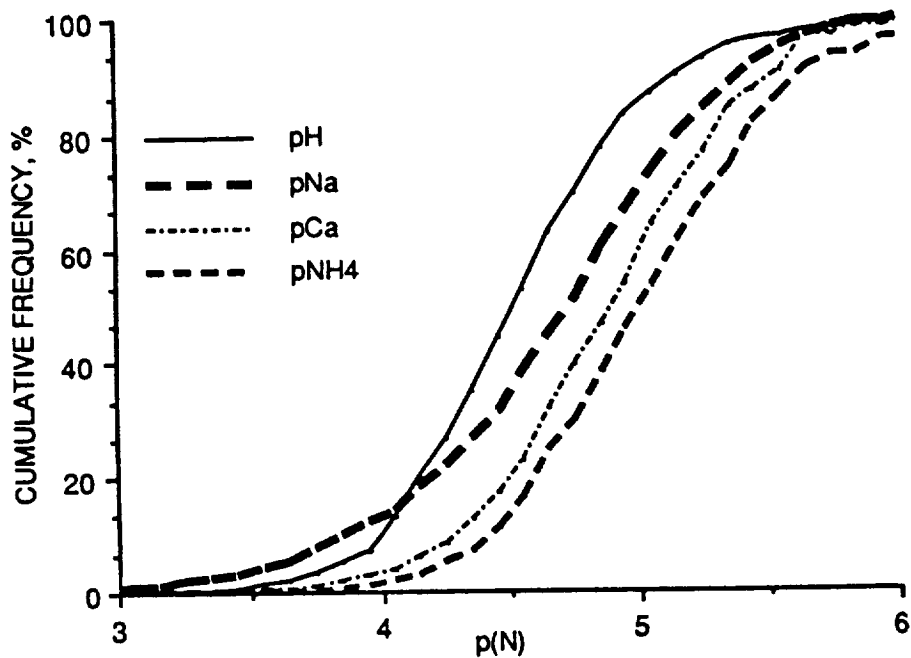
Figure 4. Ten Year Anion Concentration Distribution in Rain at UCF.

Legend:
- pCl
- pNO3
- pexcessSO4

Y-axis: CUMULATIVE FREQUENCY, %
X-axis: p(N)
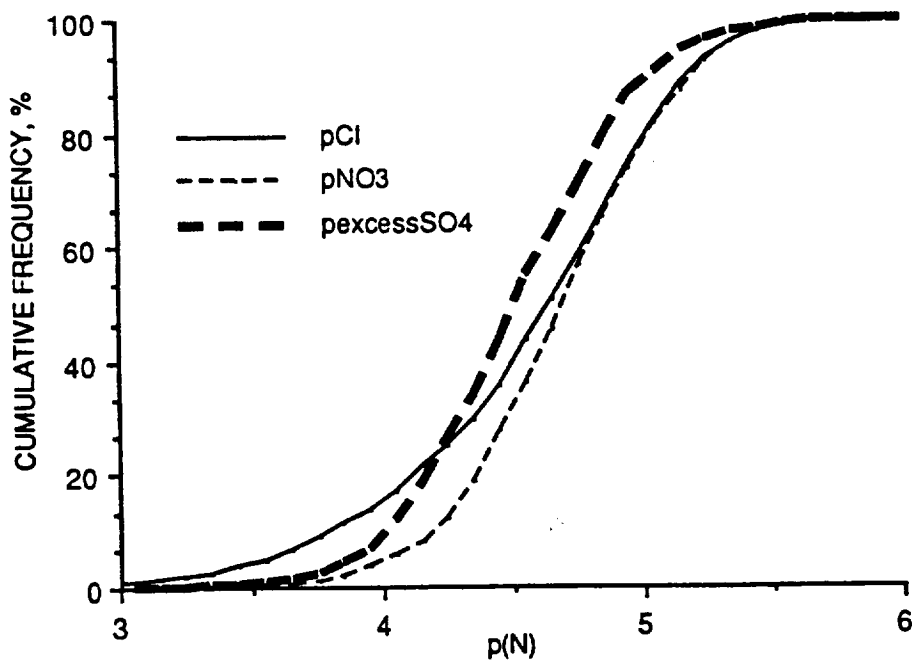
Figure 5. Comparison of Measured UCF Rainwater Acidity and Stepwise Regression Model Acidity.
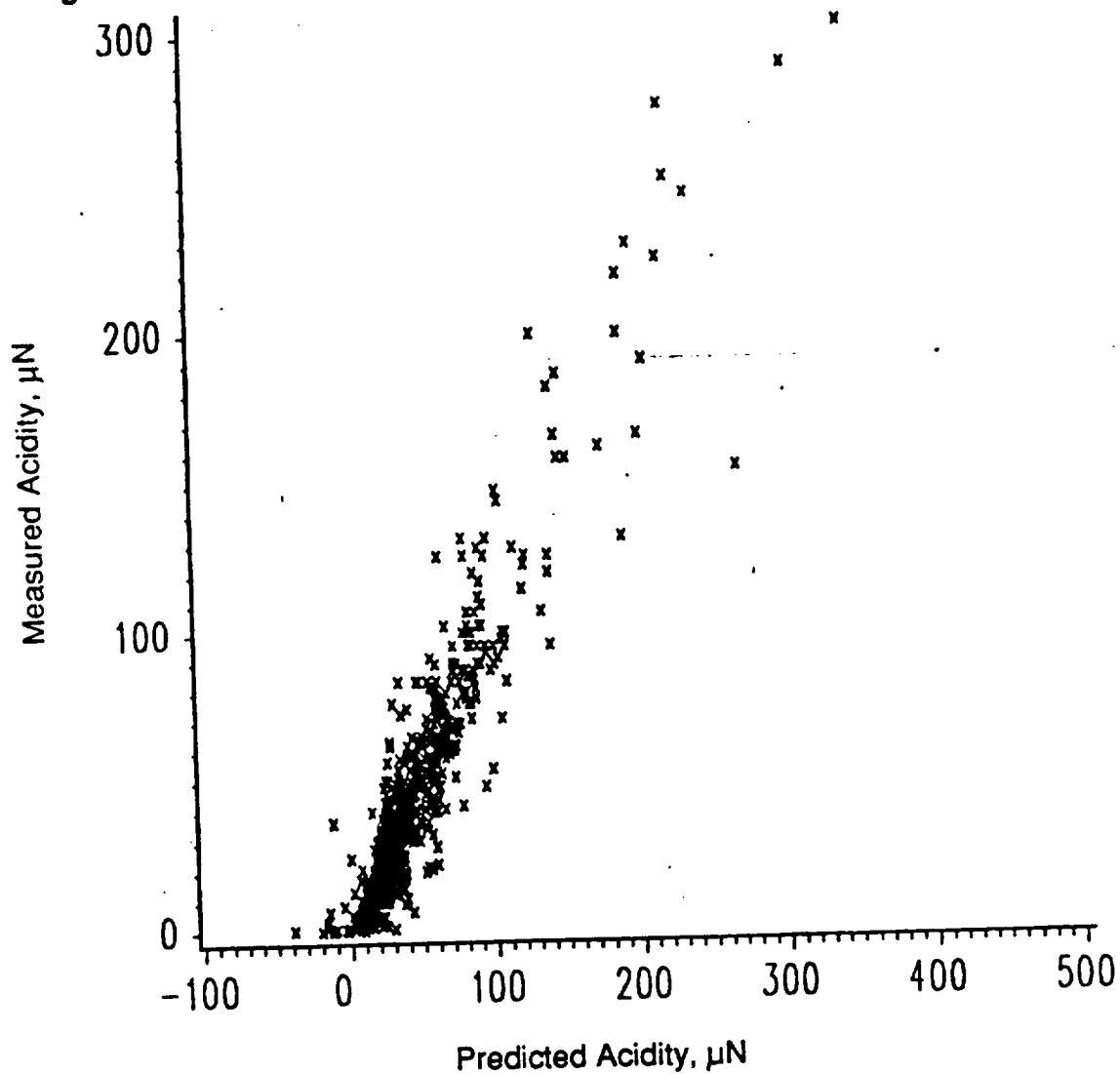
Figure 6. Annual Rainfall Amounts for UCF, KSC and NWS.
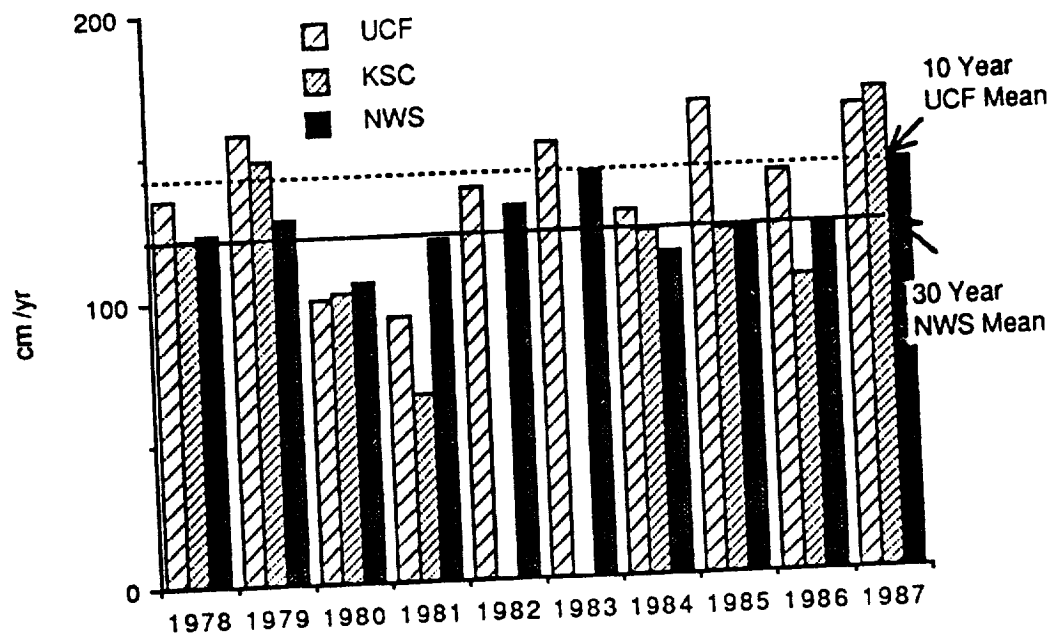
Figure 7. Monthly Rainfall Amount Averages for 1978-1987.
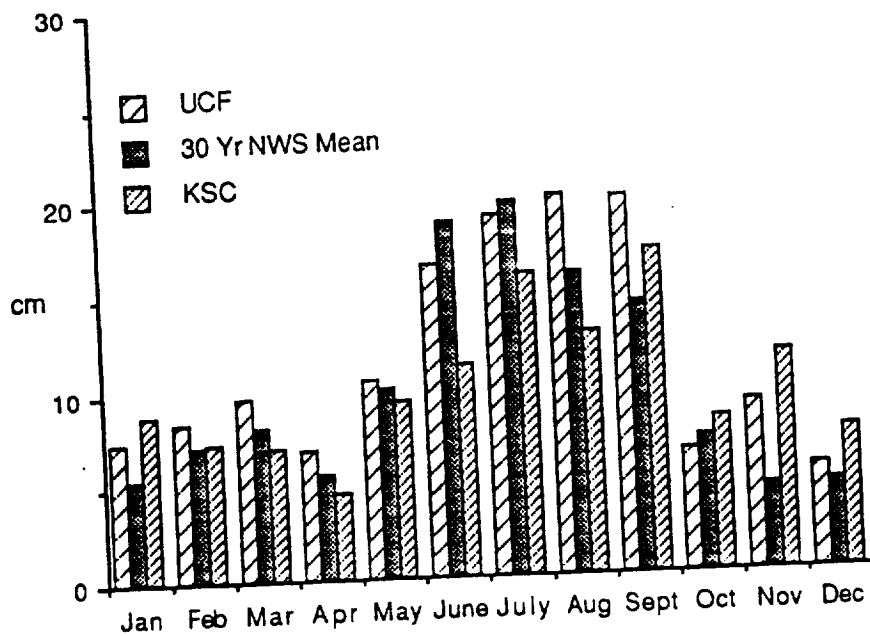
Figure 10. Annual Anion Concentrations in Rain at the University of Central Florida.

Legend: xs SO4, NO3, Cl

y-axis: µN (0 to 120)
x-axis: 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987
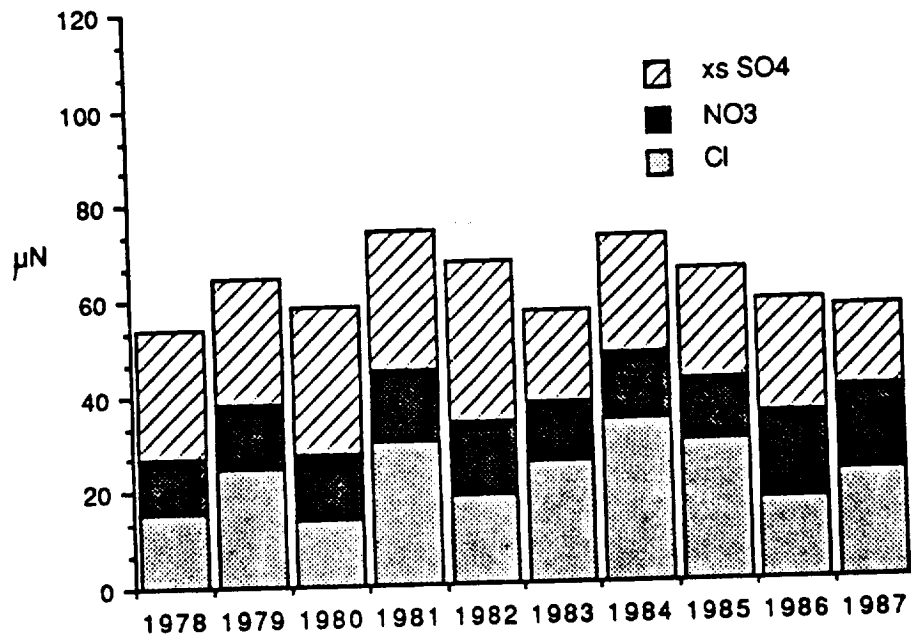
Figure 11. Annual Anion Concentrations in Rain at the Kennedy Space Center.

Legend: xs SO4, NO3, Cl

y-axis: µN (0 to 120)
x-axis: 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987
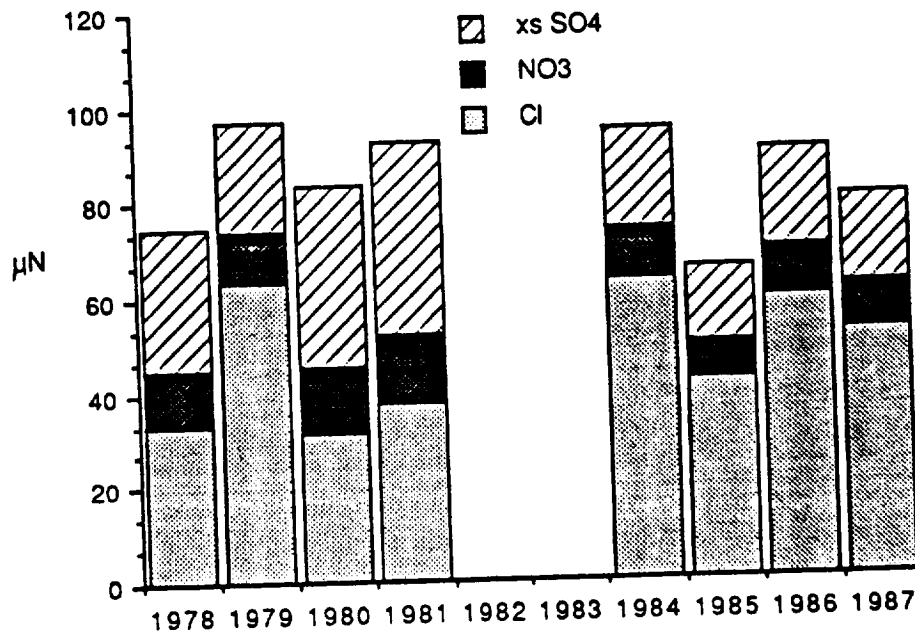
Figure 12. Annual Excess Sulfate to Nitrate Ratio in Rain at UCF and KSC.
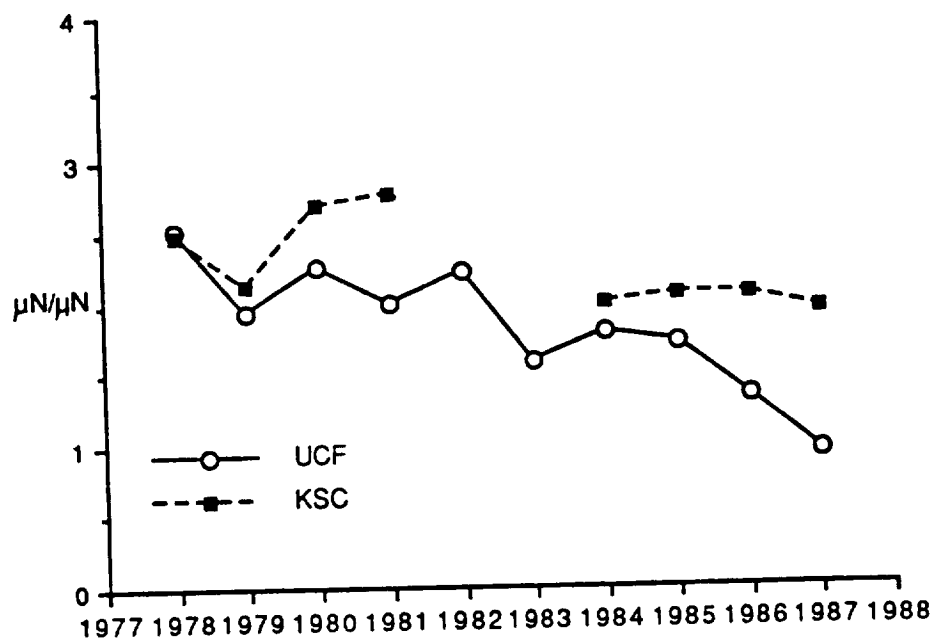
Figure 13. Monthly Excess Sulfate to Nitrate Ratios at UCF and KSC.
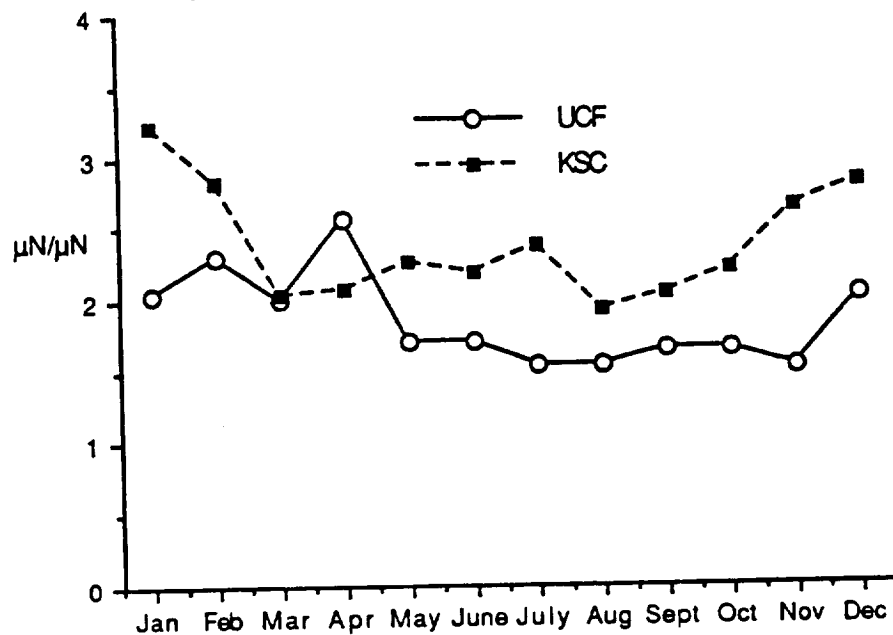
Figure 14. Annual Weighted Average Nitrate Concentrations in Rain at UCF and KSC.
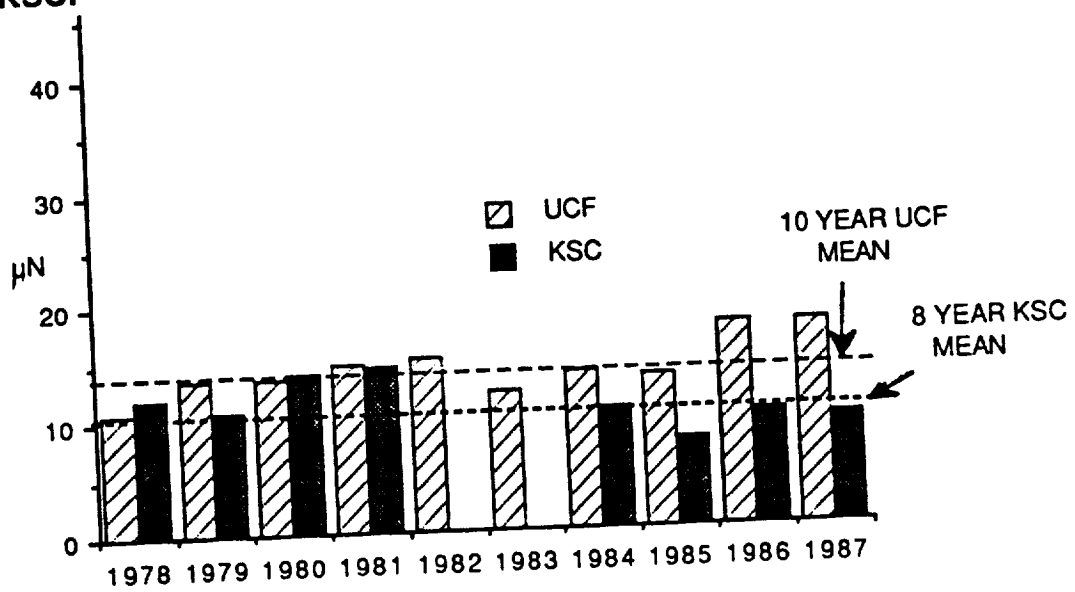
Figure 15. Annual Weighted Average Excess Sulfate Concentration in Rain at UCF and KSC.
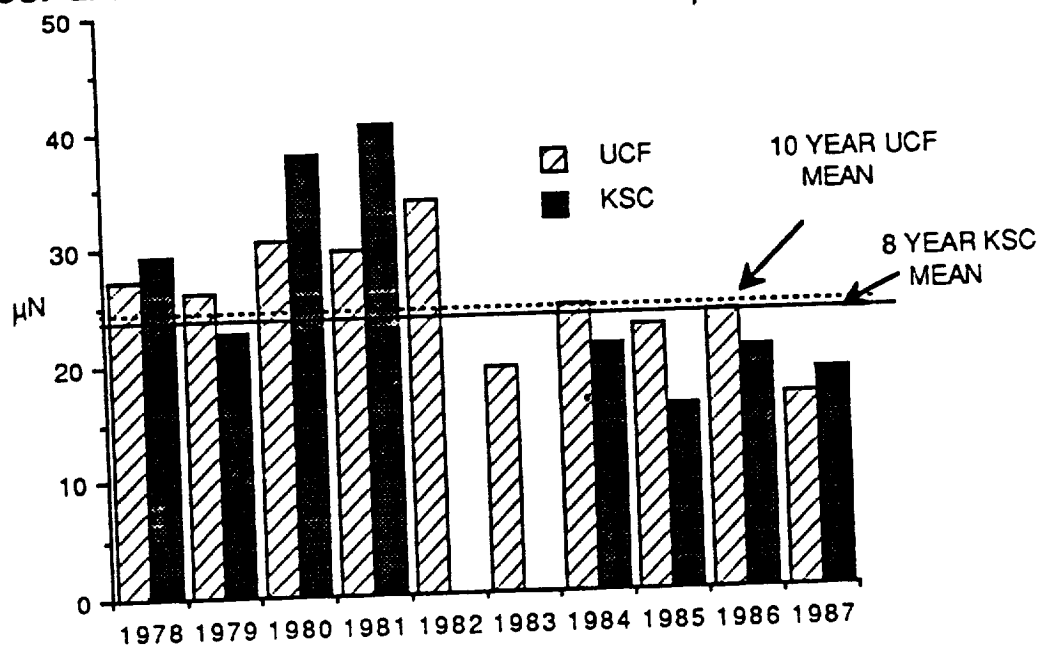
Figure 16. Monthly Rainfall Composition at UCF and KSC During 1978-1987.
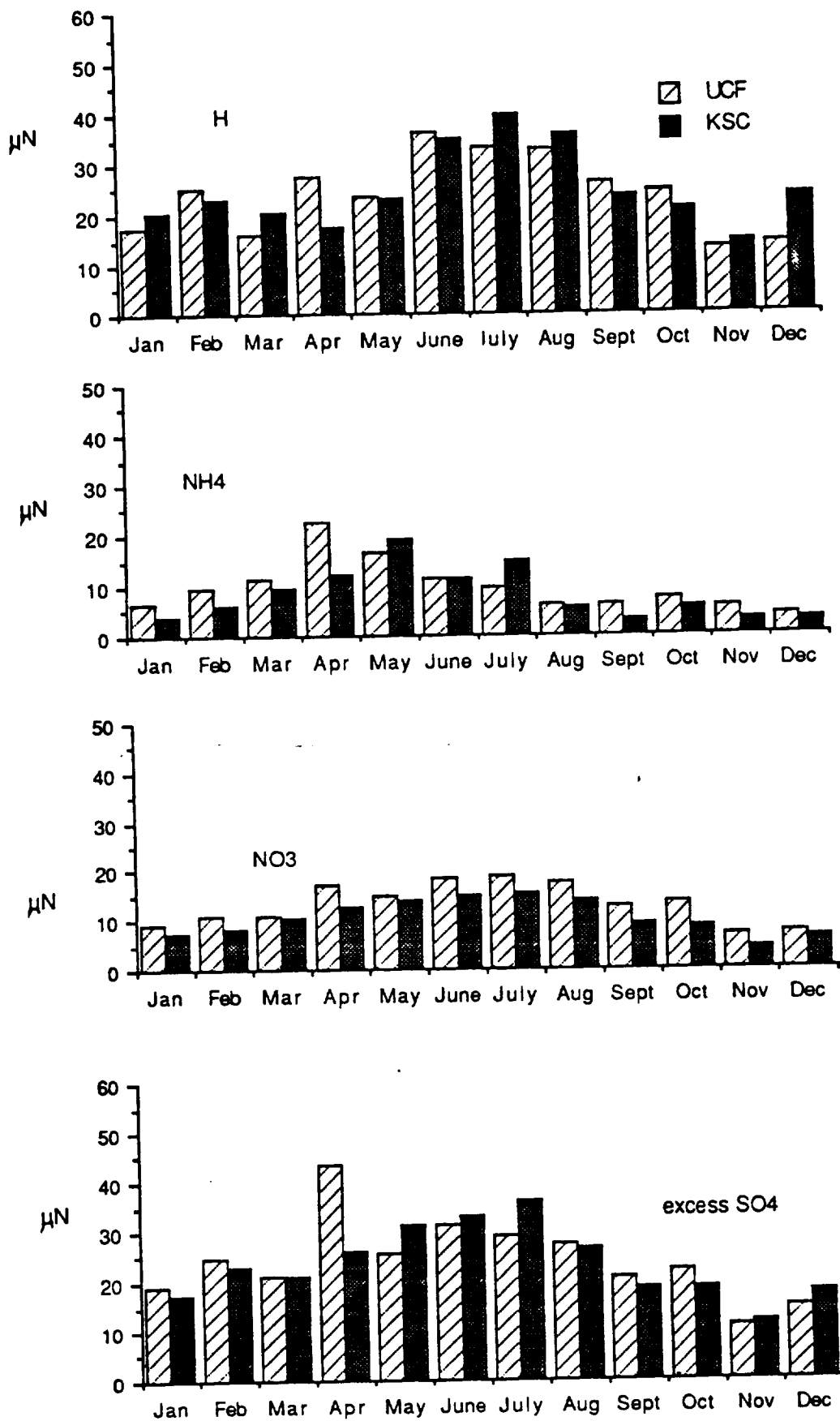
Figure 17. Annual Weighted Average Ammonium Ion Concentrations in Rain at UCF and KSC.
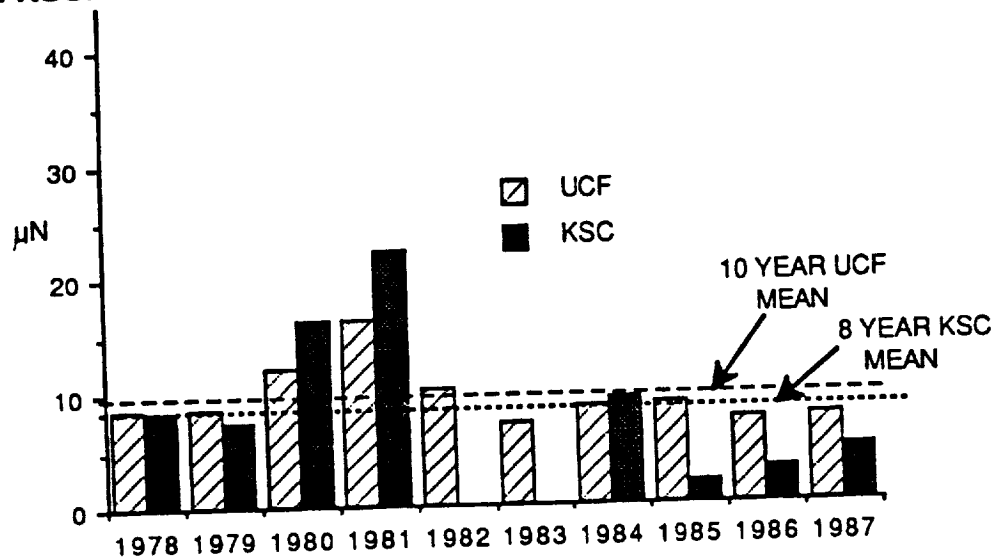
Figure 18. Monthly Weighted Average Chloride Concentration in Rain at UCF and KSC.

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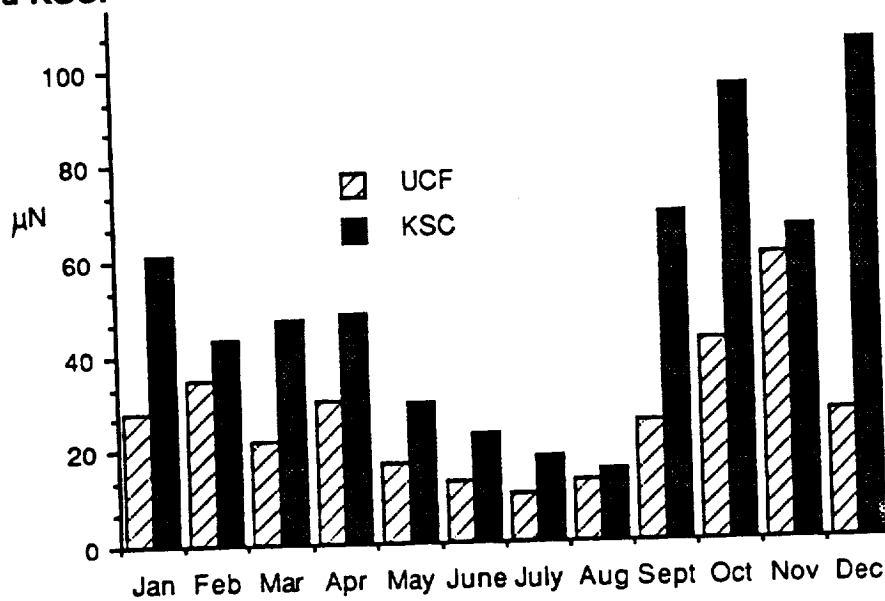
Figure 19. Monthly Precipitation Amounts and Deposition at UCF and KSC During 1978-1987.
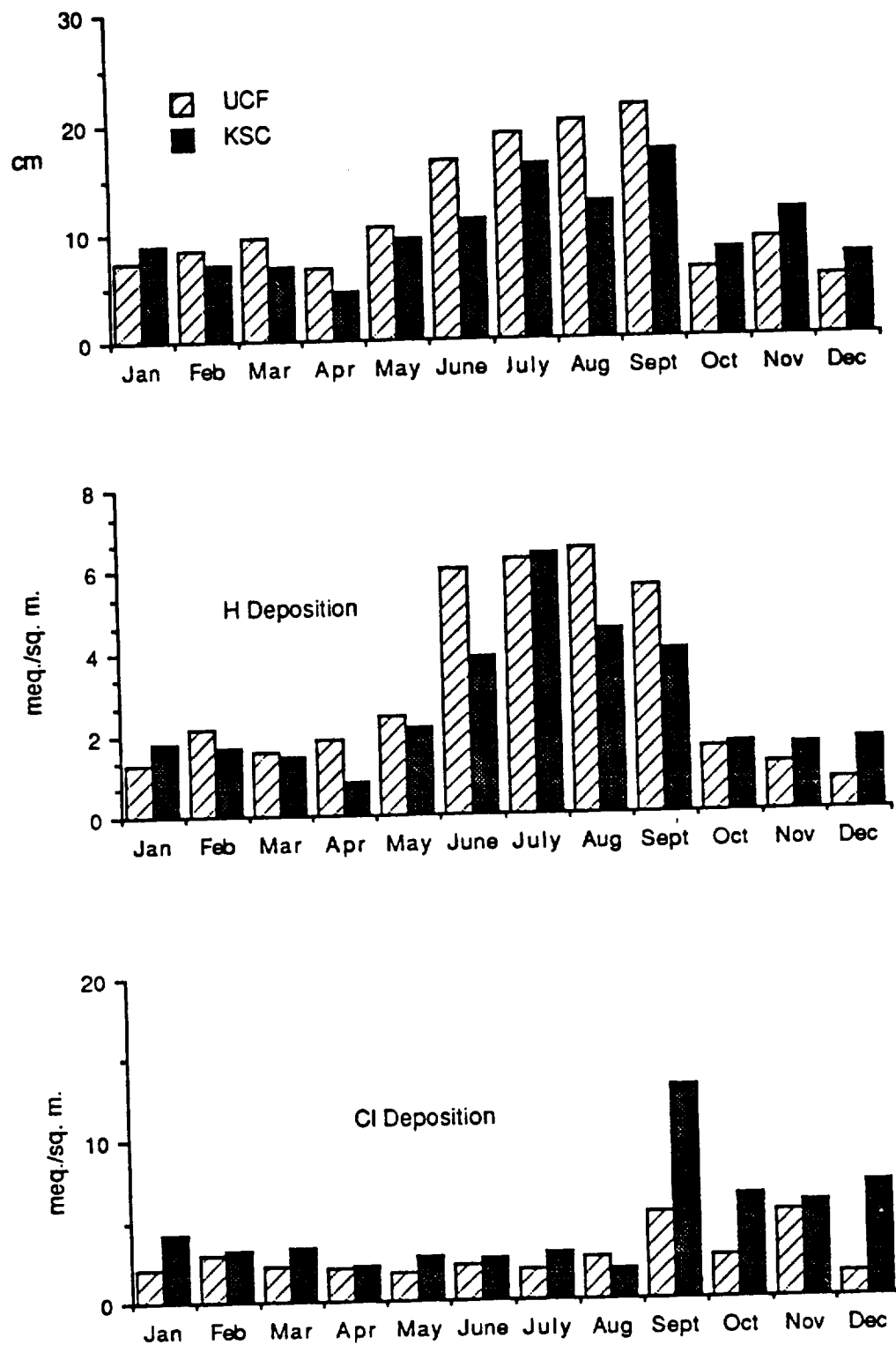
APPENDIX

APPENDIX IA. MONTHLY PRECIPITATION COMPOSITION SUMMARY FOR THE UNIVERSITY OF CENTRAL FLORIDA

MO YR	NO	CM	PH	COND UMHO/CM	DEP H MEQ/SQ M	CL/NA EQ/EQ	AN/CA EQ/EQ	COND/ PCOND
070177	12.	15.48	4.30	20.0	7.8			
080177	11.	25.13	4.42	22.0	9.6			
090177	8.	21.20	4.49	14.6	6.9			
100177	6.	1.41	4.41	17.4	0.5			
110177	5.	6.30	4.92	8.2	0.8	1.17	1.05	0.96
120177	10.	8.78	4.52	11.8	2.7	1.33	0.85	0.73
010178	7.	5.53	4.76	10.9	1.0	1.02	0.74	0.72
020178	8.	16.22	4.28	19.8	8.5	1.23	0.75	0.80
030178	4.	6.33	4.47	19.6	2.1	1.03	1.05	0.90
040178	3.	1.06	4.68	18.9	0.2	0.97	0.77	0.96
050178	5.	7.72	4.53	14.0	2.3	1.02	0.58	0.67
060178	9.	20.34	4.48	13.1	6.7	1.05	0.88	0.75
070178	14.	30.81	4.57	12.0	8.3	0.97	0.79	0.92
080178	10.	9.39	4.49	15.8	3.0	1.21	0.81	0.93
090178	7.	18.41	4.35	18.0	8.2	1.24	0.89	0.86
100178	7.	6.70	4.37	23.8	2.9	1.02	0.85	0.83
110178	1.	0.09	4.65	0.0	0.0	1.21	1.13	0.00
120178	6.	12.64	4.78	13.0	2.1	1.12	1.00	0.99
010179	9.	18.53	4.86	9.4	2.6	1.05	0.80	0.84
020179	4.	4.77	4.36	28.9	2.1	1.23	1.05	0.65
030179	3.	6.67	4.41	20.6	2.6	1.32	1.04	0.98
040179	3.	2.28	5.04	17.6	0.2	1.13	0.93	0.88
050179	14.	18.17	4.60	14.9	4.6	1.06	0.96	0.96
060179	8.	15.77	4.19	25.7	10.2	1.13	0.84	0.76
070179	15.	20.64	4.32	19.8	9.9	1.30	0.85	0.81
080179	11.	25.64	4.34	18.8	11.7	1.43	0.96	0.83
090179	9.	31.23	4.95	7.4	3.5	1.04	1.14	0.87
100179	4.	2.72	4.90	8.3	0.3	1.15	0.63	0.71
110179	6.	9.77	4.58	17.0	2.6	1.27	1.00	0.80
120179	4.	1.56	4.63	10.3	0.4	1.13	0.87	0.78
010180	6.	4.77	4.67	10.5	1.0	1.07	0.86	0.83
020180	6.	3.48	4.47	15.3	1.2	1.16	1.03	0.79
030180	5.	4.94	4.77	11.7	0.8	1.06	0.94	0.96
040180	5.	10.41	4.57	12.5	2.8	1.02	0.95	0.80
050180	10.	12.05	4.49	16.6	3.9	1.10	0.91	0.87
060180	10.	8.75	4.32	23.3	4.2	1.15	0.94	0.85
070180	8.	18.59	4.45	20.4	6.6	1.19	0.89	0.99
080180	9.	10.64	4.50	18.5	3.4	1.17	0.84	0.98
090180	9.	8.59	4.54	16.7	2.5	1.07	0.85	1.05
100180	4.	1.28	4.33	33.0	0.6	1.05	0.93	0.95
110180	4.	14.56	4.95	6.8	1.6	0.93	0.77	0.89
120180	2.	1.50	4.59	17.0	0.4	1.04	0.95	0.95
010181	4.	0.41	4.64	17.5	0.1	1.25	0.94	0.90
020181	6.	14.73	4.79	14.9	2.4	1.09	0.88	1.00
030181	4.	6.91	4.96	19.7	0.8	1.15	0.87	1.05
040181	1.	0.03	3.96	164.0	0.0	1.16	1.00	1.03
050181	3.	5.20	4.95	12.4	0.6	1.11	0.82	0.98
060181	8.	6.64	4.38	27.8	2.8	1.10	0.85	1.05

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070181	7.	10.30	4.35	22.8	4.6	1.35	0.85	0.86
080181	14.	12.16	4.40	17.9	4.8	1.32	0.84	0.86
090181	10.	16.05	4.40	17.7	6.4	1.12	0.89	0.88
100181	6.	3.72	4.10	45.6	3.0	1.15	0.93	0.93
110181	6.	9.89	5.06	13.8	0.9	1.26	1.00	0.91
120181	6.	7.80	4.92	9.7	0.9	1.12	1.00	1.03
010182	4.	5.03	5.01	8.6	0.5	1.26	1.00	0.90
020182	10.	2.67	4.50	21.2	0.8	1.26	0.96	0.91
030182	7.	12.19	4.84	12.1	1.8	1.17	0.92	0.99
040182	6.	18.63	4.38	26.6	7.8	1.26	0.87	0.90
050182	8.	13.14	4.87	7.6	1.8	1.73	0.93	1.05
060182	10.	17.70	4.67	10.3	3.8	1.30	0.71	0.80
070182	10.	24.06	4.38	21.8	10.0	1.50	1.09	1.00
080182	13.	14.59	4.28	26.4	7.7	1.33	1.02	0.98
090182	8.	22.33	4.44	20.6	8.1	1.46	1.02	1.08
100182	8.	3.44	4.65	16.6	0.8	1.23	0.97	1.05
110182	9.	2.83	4.46	23.2	1.0	1.08	0.94	1.02
120182	6.	1.92	4.79	16.0	0.3	1.13	0.99	1.03
010183	7.	5.42	4.61	22.1	1.3	1.19	0.96	0.97
020183	8.	21.59	4.94	8.2	2.5	1.19	0.88	0.79
030183	10.	12.80	4.66	14.9	2.8	1.10	0.87	0.98
040483	6.	8.02	4.95	17.9	0.9	1.21	0.63	0.94
050183	3.	4.38	4.50	20.9	1.4	1.08	0.97	1.07
060183	10.	19.23	4.68	12.5	4.0	1.58	1.04	1.04
070183	7.	10.44	4.37	23.4	4.5	1.62	1.09	1.05
080183	9.	20.56	4.62	13.0	4.9	1.55	1.15	0.94
090183	10.	15.23	4.70	13.5	3.0	1.07	0.93	1.06
100183	10.	18.55	4.98	10.3	1.9	1.02	0.93	0.98
110183	10.	5.73	4.96	11.2	0.6	1.57	1.15	0.98
120183	4.	10.42	4.96	8.6	1.1	1.15	0.90	0.89
010184	4.	4.64	4.38	23.8	1.9	1.15	1.07	0.97
020184	5.	8.25	4.88	11.3	1.1	1.13	1.00	0.96
030184	4.	2.70	4.91	12.1	0.3	1.36	1.12	1.02
040184	5.	18.36	4.63	19.2	4.3	1.20	1.15	1.08
050184	5.	12.19	4.90	11.6	1.5	1.30	0.89	1.13
060184	7.	5.06	4.49	20.4	1.6	1.27	1.06	1.08
070184	11.	30.11	4.91	9.7	3.7	1.22	1.00	1.05
080184	9.	24.09	4.54	17.0	6.9	1.35	1.05	1.09
090184	8.	12.59	4.90	16.2	1.6	1.08	0.89	1.01
100184	6.	1.48	5.09	41.6	0.1	1.15	0.94	0.95
110184	5.	8.30	4.75	28.2	1.5	1.26	0.96	0.80
120184	2.	0.45	4.83	16.1	0.1	1.28	1.05	0.99
010185	6.	2.06	4.75	20.4	0.4	1.26	1.00	1.23
020185	5.	2.67	4.95	17.1	0.3	1.39	0.92	1.11
030185	2.	7.80	5.37	5.4	0.3	0.99	0.85	1.04
040185	5.	4.50	4.62	21.8	1.1	1.26	1.02	1.01
050185	6.	14.33	4.51	19.8	4.4	1.30	0.92	0.97
060185	13.	28.77	4.51	17.7	8.9	1.67	0.92	1.02
070185	12.	11.20	4.65	13.5	2.5	1.15	0.83	1.03
080185	15.	39.41	4.79	11.5	6.4	1.40	0.93	1.07
090185	9.	43.67	4.58	21.4	11.5	1.19	1.03	1.02
100185	8.	7.94	4.72	19.1	1.5	1.25	0.99	1.21
110185	7.	5.75	4.82	20.3	0.9	1.32	1.08	1.09
120185	5.	10.38	4.98	5.8	1.1	1:62	1.04	0.97

010186	7.	21.69	4.80	10.9	3.4	1.33	1.09	0.94
020186	6.	4.69	4.95	10.8	0.5	1.42	0.95	1.10
030186	8.	8.98	4.76	15.5	1.6	1.21	0.96	1.06
040186	3.	0.72	4.78	15.6	0.1	1.59	1.12	1.15
050186	6.	4.73	4.46	25.6	1.6	1.26	1.00	1.10
060186	17.	26.95	4.34	22.3	12.3	1.53	0.92	1.01
070186	11.	11.70	4.23	33.2	6.9	1.62	1.02	1.09
080186	13.	19.84	4.65	14.0	4.4	1.51	0.95	1.09
090186	7.	15.97	4.60	14.8	4.0	1.41	0.90	1.05
100186	9.	11.45	4.45	21.1	4.1	1.30	1.01	1.12
110186	5.	6.63	5.01	7.2	0.6	1.26	0.90	1.22
120186	9.	6.97	4.83	14.4	1.0	1.12	1.01	1.05
010187	6.	6.63	4.88	10.9	0.9	1.28	1.00	1.10
020187	8.	5.38	4.44	26.9	2.0	1.02	0.94	1.08
030187	5.	26.80	5.01	9.8	2.6	1.14	0.95	1.25
040187	5.	0.81	4.55	31.0	0.2	1.15	0.90	1.13
050187	10.	12.80	4.70	15.5	2.6	1.02	0.90	1.08
060187	11.	16.91	4.43	22.0	6.3	1.30	0.96	1.05
070187	12.	22.16	4.57	16.9	6.0	1.15	1.03	1.05
080187	11.	9.19	4.36	24.6	4.0	1.78	1.08	1.10
090187	12.	27.95	4.64	12.6	6.4	1.23	0.96	1.05
100187	6.	6.55	5.09	10.5	0.5	1.09	0.86	0.97
110187	6.	26.00	5.12	11.3	2.0	1.01	0.83	0.93
120187	4.	1.05	4.65	15.4	0.2	1.03	0.88	0.80

APPENDIX IB. MONTHLY VOLUME WEIGHTED AVERAGE CONCENTRATIONS OF MAJOR CATIONS AND ANIONS IN PRECIPITATION COLLECTED AT THE UNIVERSITY OF CENTRAL FLORIDA

MICROEQUIVALENTS/LITER

MO YR	H	NA	K	CA	MG	NH4	CL	NO3	SO4	EXCESS SO4
070177	50.1									
080177	38.0									
090177	32.4									
100177	38.9									
110177	12.0	15.7	0.3	3.5	3.7	3.3	18.3	6.6	11.2	9.4
120177	30.2	17.8	1.0	6.0	4.5	2.2	23.7	9.0	18.7	16.6
010178	17.4	30.9	2.8	19.0	11.8	7.2	31.6	10.0	23.9	20.7
020178	52.5	7.8	2.8	6.0	2.5	9.4	9.6	9.8	39.4	38.4
030178	33.9	22.2	1.3	12.0	5.8	11.1	22.8	13.5	51.8	49.5
040178	20.9	21.7	2.8	25.9	6.9	33.8	21.1	21.5	41.8	39.7
050178	29.5	13.5	5.6	7.0	4.9	51.0	13.8	16.5	33.3	31.9
060178	33.1	11.3	1.0	6.5	2.9	6.7	11.8	12.3	29.8	28.6
070178	26.9	6.1	0.8	7.0	1.6	1.7	5.9	7.6	18.9	18.3
080178	32.4	13.5	1.0	8.0	4.4	3.9	16.4	13.1	21.2	19.6
090178	44.7	4.8	0.5	2.0	1.4	8.9	5.9	12.3	31.4	30.9
100178	42.7	61.7	1.5	8.0	13.4	8.3	63.2	15.0	36.6	30.1
110178	22.4	13.5	1.0	10.5	3.9	4.4	16.4	30.8	15.6	14.0
120178	16.6	30.9	1.0	5.0	7.1	2.8	34.7	6.0	22.1	18.5
010179	13.8	22.6	1.0	12.5	6.8	5.0	23.7	6.5	16.2	13.8
020179	43.7	128.3	0.8	14.0	30.8	16.6	157.4	22.7	68.1	52.7
030179	38.9	14.3	3.1	4.5	3.5	8.3	18.9	15.3	34.1	32.4
040179	9.1	90.0	0.8	12.0	22.3	3.9	102.1	7.1	18.7	8.2
050179	25.1	13.0	2.0	10.0	4.0	11.1	13.8	15.2	24.8	23.4
060179	64.6	23.9	0.8	12.0	7.1	12.2	27.1	18.9	53.5	50.7
070179	47.9	7.8	1.0	7.0	2.6	16.1	10.2	18.2	33.5	32.6
080179	45.7	8.3	2.8	8.0	2.5	5.5	11.8	19.0	34.8	33.8
090179	11.2	15.2	0.5	2.0	3.9	4.4	15.8	6.1	11.7	10.0
100179	12.6	15.2	1.0	30.9	3.4	12.8	17.5	15.6	13.1	11.3
110179	26.3	47.4	1.5	9.0	10.8	8.9	60.1	9.7	31.9	26.2
120179	23.4	10.0	1.3	6.0	2.3	7.8	11.3	9.4	21.9	20.7
010180	21.4	13.5	0.8	4.0	3.3	8.9	14.4	8.7	21.0	19.5

020180	33.9	18.3	0.8	4.5	3.9	8.9	21.1	14.4	31.2	29.1
030180	17.0	10.9	0.8	12.0	2.9	11.6	11.6	10.8	26.4	25.3
040180	26.9	13.5	0.8	6.0	2.8	9.4	13.8	11.1	26.0	24.6
050180	32.4	11.3	0.5	9.0	2.7	17.7	12.4	17.6	35.8	34.5
060180	47.9	11.3	0.3	13.5	3.6	24.9	13.0	22.9	52.9	51.5
070180	35.5	8.3	0.5	20.5	2.2	13.3	9.9	14.8	44.1	43.1
080180	31.6	11.3	0.8	23.0	4.9	7.8	13.3	19.2	33.3	32.0
090180	28.8	16.5	1.5	5.0	3.9	5.0	17.8	8.4	25.2	23.4
100180	46.8	76.5	2.0	11.0	17.4	13.9	80.7	21.8	51.0	42.7
110180	11.2	10.9	1.0	2.5	1.6	9.4	10.2	5.8	11.9	10.8
120180	25.7	29.6	0.8	6.5	7.4	10.0	30.7	12.9	31.2	28.1
010181	22.9	19.1	2.6	18.5	7.6	25.5	24.0	19.2	41.6	39.3
020181	16.2	36.1	1.3	4.5	12.0	11.6	39.5	6.6	23.9	19.9
030181	11.0	34.3	1.0	34.9	11.5	31.0	39.5	15.5	44.3	40.3
040181	109.6	626.1	11.0	54.9	153.0	30.5	727.6	64.5	170.3	95.4
050181	11.2	13.9	1.0	14.0	3.3	31.0	15.5	13.7	28.3	26.7
060181	41.7	18.7	0.8	21.5	4.8	27.7	20.6	24.5	50.8	48.7
070181	44.7	5.7	0.5	17.0	1.9	37.1	7.6	31.3	41.4	40.8
080181	39.8	10.0	0.5	9.0	2.9	12.8	13.3	16.8	29.8	28.6
090181	39.8	12.6	1.0	4.5	2.6	7.2	14.1	13.7	31.2	29.8
100181	79.4	67.8	1.8	18.0	15.1	21.6	77.8	32.3	75.4	67.4
110181	8.7	62.6	1.5	6.5	15.9	2.8	79.0	3.1	15.6	8.1
120181	12.0	17.4	0.3	7.5	4.7	2.8	19.5	5.5	19.8	17.8
010182	9.8	14.8	0.5	11.0	4.7	8.9	18.6	11.5	19.6	17.8
020182	31.6	32.6	0.8	14.0	8.6	18.9	41.2	13.7	46.8	42.9
030182	14.5	26.1	0.5	7.0	6.1	8.3	30.5	7.3	20.0	16.9
040182	41.7	30.9	1.0	25.4	8.6	29.9	38.9	17.4	62.7	59.0
050182	13.5	3.9	0.3	4.0	1.1	2.8	6.8	8.7	8.1	7.7
060182	21.4	7.4	0.3	17.5	2.7	8.9	9.6	9.7	22.3	21.4
070182	41.7	5.7	0.3	9.0	2.1	8.3	8.5	22.6	42.1	41.4
080182	52.5	9.1	0.3	14.0	2.7	6.7	12.1	25.6	49.1	48.0
090182	36.3	8.7	0.3	7.5	2.4	6.7	12.7	13.7	36.9	35.8
100182	22.4	31.7	0.5	6.0	7.5	3.9	39.2	8.7	22.1	18.3
110182	34.7	40.9	0.5	6.5	10.4	5.5	44.3	13.4	35.0	30.4
120182	16.2	43.9	1.0	8.5	9.7	3.3	49.6	10.5	21.9	16.8
010183	24.5	60.9	1.0	13.5	14.9	7.8	72.8	11.3	33.5	26.2
020183	11.5	26.1	2.6	6.5	6.4	4.4	31.0	6.9	12.9	9.8
030183	21.9	21.3	1.0	10.5	5.5	10.5	23.4	13.2	24.8	22.4
040483	11.2	26.1	3.1	48.4	8.9	44.9	31.6	20.0	37.5	34.3

Date										
050183	31.6	9.1	0.5	12.0	3.0	19.4	9.9	16.5	47.3	46.2
060183	20.9	7.0	0.3	7.5	2.3	5.0	11.0	12.1	21.4	20.6
070183	42.7	9.6	0.3	8.5	2.7	6.7	15.5	24.8	36.2	35.1
080183	24.0	12.2	0.3	5.5	3.1	2.8	18.9	14.4	21.9	20.4
090183	20.0	18.7	0.5	6.5	5.3	3.9	20.0	12.3	18.5	16.5
100183	10.5	31.7	2.0	5.0	7.7	2.2	32.4	7.9	14.6	11.2
110183	11.0	25.7	1.3	7.0	9.4	3.3	40.3	9.2	16.9	13.8
120183	11.0	25.2	2.6	3.0	5.8	4.4	29.0	6.8	11.0	8.0
010184	41.7	28.7	0.8	2.5	7.2	8.3	33.0	21.8	40.8	37.4
020184	13.2	24.8	1.0	5.5	6.3	8.3	27.9	8.2	23.1	20.2
030184	12.3	16.5	0.8	13.0	5.2	9.4	22.6	10.8	30.8	28.8
040184	23.4	13.9	0.8	15.0	4.9	16.1	16.6	17.9	50.4	48.7
050184	12.6	15.2	0.5	8.5	4.9	10.5	19.7	10.8	15.8	14.0
060184	32.4	8.7	0.5	11.5	3.3	11.1	11.0	23.6	36.9	35.8
070184	12.3	10.9	0.5	11.0	3.6	3.9	13.3	12.9	16.0	14.7
080184	28.8	5.2	0.8	5.0	1.6	9.4	7.1	15.3	30.8	30.2
090184	12.6	57.0	0.5	13.0	12.9	5.0	61.8	8.1	20.4	14.0
100184	8.1	224.4	1.0	38.9	51.7	7.8	257.5	9.7	46.2	19.7
110184	17.8	148.3	1.3	26.4	36.5	8.9	186.1	13.1	29.6	11.8
120184	14.8	31.7	0.3	21.0	7.9	11.1	40.6	18.7	32.1	28.3
010185	17.8	27.4	0.3	17.5	7.6	14.4	34.4	15.5	34.8	31.5
020185	11.2	24.3	1.0	38.4	9.5	10.5	33.8	16.3	37.1	34.1
030185	4.3	13.9	0.3	6.0	3.4	4.4	13.8	2.6	11.0	9.6
040185	24.0	40.0	0.3	12.5	11.1	20.5	50.2	20.2	39.6	34.8
050185	30.9	15.2	0.3	14.5	4.7	21.1	19.7	16.5	43.1	41.3
060185	30.9	6.1	0.5	9.0	3.9	12.8	10.2	16.6	31.2	30.5
070185	22.4	7.4	0.5	15.0	2.3	6.1	8.5	21.3	15.0	14.1
080185	16.2	10.9	0.5	11.0	3.0	5.0	15.2	12.3	16.0	14.7
090185	26.3	50.0	0.5	5.0	10.7	7.2	59.5	12.4	31.0	25.0
100185	19.1	30.0	0.5	11.5	7.2	8.9	37.5	14.2	24.6	21.0
110185	15.1	57.4	0.8	7.5	14.1	8.3	75.9	9.8	26.2	19.4
120185	10.5	4.3	0.3	2.0	1.3	2.8	7.1	4.5	10.4	9.9
010186	15.8	19.6	0.3	5.0	4.4	4.4	25.9	7.1	21.0	18.7
020186	11.2	13.5	0.5	14.0	4.4	6.7	19.2	9.5	18.9	17.3
030186	17.4	26.5	0.5	8.5	7.2	12.8	32.1	13.5	24.4	21.2
040186	16.6	10.4	0.5	19.0	3.8	10.0	16.6	16.3	34.6	33.3
050186	34.7	22.2	0.3	14.0	5.8	20.5	27.9	25.2	43.9	41.3
060186	45.7	6.1	0.3	7.0	2.0	7.2	9.3	23.2	30.0	29.3
070186	58.9	7.0	0.3	17.5	3.4	10.5	11.3	35.5	52.5	51.6

Date										
080186	22.4	7.8	0.5	8.0	3.1	6.1	11.8	16.6	17.3	16.3
090186	25.1	10.0	0.3	9.5	3.6	5.0	14.1	19.7	14.6	13.4
100186	35.5	6.5	0.3	7.5	2.4	9.4	8.5	19.5	34.4	33.6
110186	9.8	7.4	0.3	2.0	1.6	3.3	9.3	7.7	5.0	4.1
120186	14.8	34.8	0.3	6.5	7.8	6.7	38.9	12.4	20.0	16.0
010187	13.2	13.9	0.5	6.5	3.9	7.2	17.8	11.1	16.0	14.4
020187	36.3	37.0	1.0	11.0	9.4	16.6	37.5	30.0	37.7	33.8
030187	9.8	12.2	0.3	4.0	3.2	8.9	13.8	9.5	12.9	11.5
040187	28.2	33.5	1.3	41.4	10.2	34.4	38.6	36.5	59.5	55.6
050187	20.0	27.0	0.5	6.0	6.2	8.9	27.4	16.5	18.1	15.3
060187	37.2	9.6	0.3	11.5	3.0	15.0	12.4	31.9	29.4	28.2
070187	26.9	11.3	0.3	11.5	3.4	7.2	13.0	24.8	24.4	23.0
080187	43.7	3.5	0.3	13.0	2.3	6.1	6.2	35.0	33.3	32.9
090187	22.9	4.3	0.5	6.0	1.6	5.0	5.4	19.7	13.7	13.2
100187	8.1	41.7	1.3	5.0	10.0	4.4	45.4	6.6	8.5	3.9
110187	7.6	56.1	1.0	4.0	13.4	2.8	56.4	4.7	9.8	4.0
120187	22.4	48.3	1.3	10.5	11.4	9.4	49.9	14.4	27.1	21.9

APPENDIX IC. MONTHLY PRECIPITATION COMPOSITION SUMMARY FOR
THE KENNEDY SPACE CENTER

MO YR	NO	CM	PH	COND UMHO/CM	DEP H MEQ/SQ M	CL/NA EQ/EQ	AN/CA EQ/EQ	COND/ PCOND
100177	5.	4.52	4.25	32.9	2.5	0.81	0.77	0.98
110177	6.	18.48	5.10	6.6	1.5	1.12	0.87	0.99
120177	12.	10.09	4.66	13.9	2.2	1.05	1.07	0.94
010178	5.	5.02	4.66	14.0	1.1	0.90	1.02	0.86
020178	9.	12.94	4.42	18.7	4.9	1.03	0.83	0.93
030178	8.	7.69	4.47	21.7	2.6	1.60	1.13	0.90
040178	3.	0.42	4.74	36.1	0.1	1.20	0.89	1.13
050178	7.	8.00	4.32	34.6	3.8	1.18	0.79	1.13
060178	9.	15.83	4.58	17.1	4.2	0.99	0.81	1.15
070178	10.	26.31	4.32	23.3	12.6	1.08	0.73	0.98
080178	4.	10.06	4.39	21.1	4.1	1.07	0.85	1.04
090178	8.	10.23	4.44	22.8	3.7	1.12	1.03	1.05
100178	8.	12.89	4.63	18.0	3.0	1.07	0.91	0.95
110178	7.	2.48	4.56	32.1	0.7	1.01	0.87	1.11
120178	4.	9.78	5.00	20.8	1.0	0.98	0.87	0.97
010179	6.	19.81	4.76	13.5	3.4	0.99	0.84	0.91
020179	4.	2.73	4.37	30.3	1.2	1.10	0.94	0.98
030179	3.	2.53	4.56	21.0	0.7	1.06	0.99	0.98
040179	3.	2.52	5.11	39.8	0.2	1.05	0.93	1.06
050179	10.	26.11	4.83	15.4	3.9	1.10	0.94	1.05
060179	10.	10.09	4.56	21.3	2.8	1.19	0.98	1.05
070179	9.	18.72	4.32	25.2	9.0	1.05	0.89	1.02
080179	11.	24.59	4.47	20.4	8.3	1.00	0.84	1.11
090179	5.	25.55	5.13	34.3	1.9	1.02	0.89	1.09
100179	5.	1.78	4.97	19.1	0.2	0.99	0.87	1.11
110179	6.	11.84	4.75	14.3	2.1	1.13	0.92	0.73
120179	6.	2.38	4.51	20.5	0.7	1.14	1.01	0.94
010180	5.	9.00	4.78	10.8	1.5	1.09	0.97	1.04
020180	6.	10.11	4.59	15.3	2.6	1.06	0.90	0.90
030180	6.	5.22	4.58	15.9	1.4	1.03	0.93	0.90
040180	6.	4.38	4.49	29.8	1.4	1.07	0.91	1.13
050180	7.	9.20	4.40	25.2	3.7	1.10	0.95	1.06
060180	9.	12.70	4.14	47.1	9.2	1.24	0.98	1.14
070180	8.	13.44	4.55	19.4	3.8	1.08	0.78	1.01
080180	6.	5.95	4.73	12.3	1.1	1.14	0.88	1.12
090180	9.	8.27	4.84	13.7	1.2	0.97	0.98	1.14
100180	8.	8.00	4.45	29.8	2.8	1.08	0.87	1.09
110180	3.	8.91	4.88	10.5	1.2	0.98	0.92	0.98
120180	7.	6.44	4.27	41.6	3.5	1.03	0.90	0.89
010181	4.	0.38	4.38	22.5	0.2	1.23	1.03	0.93
020181	5.	9.70	4.91	13.7	1.2	1.09	0.82	0.92
030181	5.	2.91	4.96	35.3	0.3	1.12	0.79	0.97
040181	3.	0.59	4.31	40.6	0.3	1.13	0.99	0.97
050181	3.	1.70	4.94	25.1	0.2	1.04	0.97	1.18
060181	5.	8.63	4.55	20.0	2.4	1.13	0.81	1.06
070181	4.	14.30	4.30	27.8	7.2	1.37	0.88	0.98
080181	3.	10.78	4.55	19.7	3.0	1.05	0.82	1.07
090181	5.	13.25	4.32	26.0	6.3	1.28	0.94	1.05

100181	4.	3.66	4.41	46.7	1.4	1.26	1.08	1.01
010184	0.	8.69	4.49	32.6	2.8	1.18	1.04	0.91
020184	0.	10.48	5.04	15.0	1.0	1.18	1.10	1.04
030184	0.	1.61	4.94	20.7	0.2	1.16	0.95	1.15
040184	0.	12.02	4.94	14.0	1.4	1.17	0.99	0.98
050184	0.	17.56	5.01	8.0	1.7	1.20	1.02	1.00
060184	0.	2.83	4.17	28.3	1.9	1.16	0.81	0.80
070184	0.	17.83	4.89	13.2	2.3	1.22	0.61	0.91
080184	0.	14.86	4.28	21.7	7.8	1.37	0.83	0.88
090184	0.	18.48	4.70	22.0	3.7	1.18	0.99	0.94
100184	0.	8.81	5.08	34.8	0.7	1.24	1.04	1.03
110184	0.	6.45	5.09	10.3	0.5	1.15	0.98	0.96
120184	0.	0.53	4.44	40.3	0.2	1.07	0.94	0.82
010185	0.	1.61	5.13	20.4	0.1	1.11	0.95	0.91
020185	0.	1.61	5.04	16.8	0.1	1.21	0.98	0.88
030185	0.	10.98	5.09	5.4	0.9	1.14	0.86	0.83
040185	0.	10.70	4.85	8.4	1.5	1.22	0.90	0.76
050185	0.	4.38	4.54	20.3	1.3	1.28	1.03	0.95
060185	0.	14.86	4.62	13.2	3.6	1.30	0.92	0.89
070185	0.	14.16	4.42	20.0	5.4	1.27	0.97	0.97
080185	0.	14.20	4.48	16.3	4.7	1.19	0.82	0.91
090185	0.	16.19	4.85	7.1	2.3	1.22	0.93	0.41
100185	0.	8.98	4.80	16.7	1.4	1.19	0.96	0.98
110185	0.	11.20	4.75	21.5	2.0	1.22	1.05	1.07
120185	0.	11.36	4.77	6.0	1.9	1.15	0.66	0.72
010186	3.	17.83	4.69	13.5	3.6	1.09	0.87	0.75
020186	4.	4.53	4.97	7.5	0.5	1.11	0.88	0.89
030186	4.	4.33	4.79	15.5	0.7	1.20	1.04	0.98
040186	3.	1.66	4.37	28.3	0.7	1.15	1.06	1.04
050186	4.	4.59	4.47	22.6	1.6	1.19	1.00	0.88
060186	4.	11.95	4.47	18.2	4.1	1.25	1.01	0.94
070186	5.	11.31	4.42	17.1	4.3	1.20	1.00	0.85
080186	4.	12.52	4.66	10.6	2.7	1.11	0.71	0.95
090186	5.	5.17	4.46	23.0	1.8	1.24	0.99	0.97
100186	4.	3.56	4.24	42.1	2.1	1.17	0.98	0.94
110186	4.	12.02	4.67	13.5	2.6	1.20	0.83	0.86
120186	5.	14.20	4.51	30.6	4.4	1.24	1.01	0.84
010187	4.	8.66	4.70	15.2	1.7	1.22	0.97	0.79
020187	4.	5.89	4.49	19.8	1.9	1.22	0.98	0.79
030187	5.	20.50	4.65	14.5	4.6	1.18	0.88	0.81
040187	3.	4.44	4.78	13.1	0.7	1.14	1.13	0.96
050187	3.	3.47	4.51	32.2	1.1	0.98	0.75	1.14
060187	4.	12.39	4.62	13.1	3.0	1.19	0.93	0.94
070187	4.	12.33	4.29	24.6	6.3	1.20	0.96	0.92
080187	3.	8.61	4.31	24.5	4.2	1.17	1.03	0.96
090187	6.	39.91	4.55	14.2	11.2	1.19	0.93	0.97
100187	4.	16.95	4.95	15.9	1.9	1.19	0.96	1.06
110187	4.	27.34	5.04	13.6	2.5	1.21	0.98	0.93
120187	5.	7.45	5.16	15.5	0.5	1.20	0.99	0.89

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APPENDIX ID.   MONTHLY VOLUME WEIGHTED AVERAGE CONCENTRATIONS OF MAJOR CATIONS AND ANIONS IN
PRECIPITATION COLLECTED AT THE KENNEDY SPACE CENTER

MICROEQUIVALENTS/LITER

MO YR	H	NA	K	CA	MG	NH4	CL	NO3	SO4	EXCESS SO4
100177	56.2	62.6	1.5	5.5	19.7	7.2	50.8	17.4	43.1	37.9
110177	7.9	16.1	1.0	6.0	3.6	1.7	18.0	3.5	7.3	5.4
120177	21.9	30.0	0.8	2.5	6.8	2.8	31.6	6.9	21.7	18.4
010178	21.9	33.5	1.0	7.0	7.5	7.2	30.2	8.5	25.8	22.7
020178	38.0	20.4	0.5	4.0	5.5	6.1	21.1	8.1	31.2	29.1
030178	33.9	30.9	2.3	12.0	10.3	10.0	49.4	20.0	42.1	38.4
040178	18.2	49.6	4.6	58.9	15.8	58.8	59.5	31.1	88.1	82.1
050178	47.9	24.3	2.3	16.0	7.6	39.4	28.8	23.1	55.6	52.7
060178	26.3	13.0	0.8	10.0	3.0	6.7	13.0	12.4	23.1	21.8
070178	47.9	9.1	0.5	16.0	2.2	9.4	9.9	11.5	40.0	39.0
080178	40.7	11.3	1.3	7.0	3.0	4.4	12.1	11.8	32.3	31.0
090178	36.3	26.1	1.0	8.0	7.0	3.9	29.3	13.7	31.6	28.6
100178	23.4	53.0	1.3	5.0	12.3	2.8	56.7	8.5	23.1	17.3
110178	27.5	108.3	2.6	8.0	24.6	2.8	109.7	12.1	29.4	18.1
120178	10.0	110.4	2.8	7.5	23.2	2.2	108.6	4.8	20.8	9.6
010179	17.4	47.0	2.3	4.0	10.3	2.2	46.5	6.3	16.7	11.9
020179	42.7	60.9	1.5	12.5	14.7	13.3	67.1	15.3	52.1	45.1
030179	27.5	43.9	1.5	12.5	10.9	6.7	46.5	18.1	33.5	28.7
040179	7.8	211.7	4.6	14.0	46.9	2.2	221.7	7.1	33.1	10.3
050179	14.8	25.2	2.0	8.0	6.7	22.2	27.6	13.2	32.3	29.4
060179	27.5	40.4	3.1	7.0	10.2	5.5	47.9	9.2	29.8	24.9
070179	47.9	20.4	1.3	7.0	5.3	5.0	21.4	16.0	36.6	34.4
080179	33.9	13.5	0.8	12.5	4.5	4.4	13.5	14.4	29.4	28.0
090179	7.4	176.1	5.9	12.0	39.9	1.7	180.2	5.2	29.1	10.6
100179	10.7	50.9	5.6	5.5	13.5	26.6	50.5	15.2	31.9	26.7
110179	17.8	66.1	2.0	8.0	15.0	6.1	74.7	6.5	23.5	15.8
120179	30.9	41.3	1.5	7.5	10.4	6.1	47.1	13.1	34.1	29.3
010180	16.6	13.5	1.0	2.0	2.6	6.7	14.7	7.1	17.7	16.2
020180	25.7	33.0	1.0	4.5	6.6	5.5	35.0	8.1	24.4	20.8
030180	26.3	18.7	1.0	13.5	5.1	12.2	19.2	11.9	36.0	34.0
040180	32.4	48.3	1.3	18.5	12.2	21.6	51.6	20.6	47.5	42.2
050180	39.8	10.0	1.5	7.5	3.0	28.8	11.0	20.6	52.1	50.9

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060180	72.4	14.8	1.3	17.5	5.8	36.6	18.3	29.8	87.0	85.3
070180	28.2	13.0	1.8	18.5	4.7	24.4	14.1	13.4	40.8	39.4
080180	18.6	10.4	0.8	8.5	3.2	3.3	11.8	10.8	16.4	15.2
090180	14.5	30.4	1.3	5.5	7.2	1.7	29.6	8.7	18.5	15.5
100180	35.5	46.1	7.7	10.5	12.4	22.2	49.6	14.0	52.7	47.6
110180	13.2	25.7	1.0	3.5	4.9	6.1	25.1	6.9	17.7	15.1
120180	53.7	141.7	5.4	6.0	34.5	11.1	145.5	12.1	63.9	48.9
010181	41.7	11.7	1.0	17.5	5.4	10.0	14.4	16.0	55.8	54.4
020181	12.3	51.7	1.5	8.0	17.4	5.5	56.1	3.1	17.5	11.7
030181	11.0	107.4	2.8	55.9	30.6	70.4	119.9	29.0	68.9	56.6
040181	49.0	86.1	3.3	20.0	18.3	31.6	97.6	31.8	70.0	59.9
050181	11.5	26.5	1.0	19.0	8.0	63.8	27.6	23.2	69.7	66.9
060181	28.2	20.4	1.3	12.0	5.2	20.0	23.1	11.9	33.5	31.1
070181	50.1	7.4	1.5	11.5	3.4	32.2	10.2	20.3	60.6	59.7
080181	28.2	17.0	0.8	10.0	5.0	21.1	17.8	14.0	34.6	32.7
090181	47.9	14.3	0.8	2.5	3.3	13.3	18.3	12.9	45.8	44.1
100181	38.9	154.4	3.6	11.0	33.2	14.4	194.3	17.9	59.1	40.6
010184	32.4	119.6	3.1	9.5	27.3	7.2	141.3	20.6	45.0	30.6
020184	9.1	49.6	1.8	10.5	12.3	2.2	58.4	7.6	27.7	21.7
030184	11.5	66.1	2.3	16.0	17.1	2.2	77.0	2.7	29.8	21.9
040184	11.5	29.1	1.5	15.5	8.5	15.5	34.1	15.0	31.6	28.2
050184	9.8	18.3	1.0	4.0	4.3	1.1	22.0	1.6	15.4	13.2
060184	67.6	27.0	1.5	15.5	8.9	12.2	31.3	26.9	48.7	45.5
070184	12.9	24.8	4.3	13.5	9.0	33.8	30.2	9.5	20.4	17.4
080184	52.5	7.4	0.5	5.0	2.6	7.8	10.2	19.7	33.1	32.2
090184	20.0	83.9	2.3	7.0	20.5	2.8	98.7	9.0	27.7	17.6
100184	8.3	172.2	4.1	11.5	40.1	1.7	212.9	4.5	30.0	9.3
110184	8.1	40.0	1.8	3.5	9.0	2.2	46.0	3.9	13.5	8.8
120184	36.3	159.6	7.4	39.9	50.8	10.0	170.6	31.3	83.7	66.1
010185	7.4	93.5	3.3	18.5	28.1	8.9	103.8	10.6	36.6	26.0
020185	9.1	52.6	3.1	33.9	15.0	10.5	63.4	18.5	40.2	33.9
030185	8.1	19.6	0.5	1.5	4.5	0.6	22.3	0.6	7.1	4.8
040185	14.1	27.8	0.8	3.0	6.5	3.3	33.8	4.2	11.9	8.5
050185	28.8	26.1	1.5	17.5	7.3	13.9	33.3	26.6	37.9	34.8
060185	24.0	14.8	1.3	12.5	5.1	3.3	19.2	11.9	25.0	23.2
070185	38.0	18.7	0.5	7.5	5.8	3.3	23.7	20.3	27.3	25.0
080185	33.1	19.1	0.8	10.5	5.8	0.0	22.8	10.2	23.7	21.4
090185	14.1	68.3	1.5	8.0	16.1	0.0	83.5	2.1	14.4	6.2
100185	15.8	60.9	1.3	6.0	14.4	0.0	72.2	4.5	17.7	10.4

110185	17.8	70.9	1.0	6.0	16.9	0.0	86.3	2.1	29.4	20.9
120185	17.0	9.6	0.3	2.0	2.6	0.0	11.0	1.3	8.5	7.4
010186	20.4	57.8	1.5	4.5	14.0	1.7	62.9	1.9	21.9	15.4
020186	10.7	13.5	1.5	7.0	4.1	5.5	14.9	6.3	16.0	14.5
030186	16.2	43.5	2.0	8.0	10.7	2.8	52.2	12.1	22.3	17.1
040186	42.7	31.3	1.3	12.5	9.0	10.5	36.1	24.7	53.3	49.6
050186	33.9	49.6	1.8	12.0	12.3	10.5	58.9	22.6	38.3	32.4
060186	33.9	22.2	0.5	4.5	5.8	4.4	27.6	14.7	29.4	26.7
070186	38.0	14.3	0.5	8.5	4.1	2.2	17.2	15.2	35.0	33.3
080186	21.9	12.2	0.3	4.5	3.3	1.1	13.5	4.5	12.5	11.1
090186	34.7	45.7	1.3	8.5	11.5	2.2	56.7	19.4	26.9	21.4
100186	57.5	116.1	3.3	9.5	27.1	5.0	135.6	26.3	52.9	39.0
110186	21.4	37.4	2.8	6.0	9.0	3.3	44.8	5.3	16.0	11.5
120186	30.9	135.2	3.1	8.0	32.1	2.2	168.4	9.0	35.6	19.4
010187	20.0	60.0	1.8	5.5	14.0	3.3	73.3	5.8	21.9	14.7
020187	32.4	52.2	1.8	9.0	12.3	11.6	63.4	17.7	36.0	29.8
030187	22.4	44.8	1.5	5.5	10.7	7.8	53.0	8.2	20.2	14.8
040187	16.6	13.9	0.8	11.0	4.1	13.3	15.8	12.7	38.7	37.1
050187	30.9	95.7	2.6	9.5	23.0	9.4	93.9	10.6	24.4	14.7
060187	24.0	16.1	0.5	3.0	4.1	6.7	19.2	11.6	19.6	17.6
070187	51.3	17.4	0.5	7.0	4.9	8.3	20.9	20.5	44.6	42.5
080187	49.0	16.1	0.5	8.5	4.1	5.0	18.9	25.8	40.8	38.9
090187	28.2	12.6	0.3	3.0	3.3	2.8	14.9	11.3	20.4	18.9
100187	11.2	60.4	1.5	3.5	14.0	1.7	71.6	3.9	13.5	6.3
110187	9.1	63.0	1.5	3.5	14.8	1.7	76.4	2.6	12.5	4.9
120187	6.9	82.2	2.0	9.0	18.9	1.7	98.4	2.7	18.1	8.3

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16. Abstract

Rainfall has been collected on the University of Central Florida (UCF) campus near Orlando since July 1977 and at the Kennedy Space Center (KSC), Florida since August 1977. Since November 1983, the KSC site has been affiliated with the National Atmospheric Deposition Network. Annual volume weighted pH has been slightly above the 10 year mean of 4.58 during four of the past five years. Nitrate concentrations have risen somewhat during recent years while excess sulfate concentrations have remained below the 10 year mean during four of the past years. These observations hold for both the UCF and KSC data. The distribution of individual sample pH has been nearly identical at UCF and KSC. Stepwise regression suggests that sulfate, nitrate, ammonium ion, and calcium play major roles in the description of rainwater acidity. Annual acid deposition and annual rainfall have varied from 30 to 50 meq/m2-yr and 100 to 180 cm/yr, respectively. Sea salt comprises about 25% (UCF) and greater than 50% (KSC) of total ionic composition.

17. Key Words (Suggested by Author(s))

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